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Operations Manual for a Compact Electromechanical Fatigue Testing Machine

Leopold Sponder

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DSTO-GD-0036

ABSTRACT

This document gives details of the design and operation of two recently developed load controlled electromechanical shaker systems. These systems have been designed to test materials including composites, alloys and pure metals with either three or four point bending loads. One system (Mk I) is designed for room temperature testing only and the other (Mk II) can also be used at elevated temperatures.

The electronic control and drive circuits include new designs by the author, published designs modified by the author and circuits developed earlier at AMRL. The loading frame and ancillary hardware were designed and built at AMRL. [1]

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EXECUTIVE SUMMARY

The effect of cyclic loads on materials and structures gives important engineering data about their susceptibility to fatigue. This document gives some pertinent details about the design and operation of two testing machines, developed in-house at AMRL.

These machines have been designed to fatigue small specimens in a controlled way using cyclic loads. The test specimens, in the shape of small beams, (100mm by 4mm by 2mm approx.) are suspended at their ends and loads are applied at their centre on one side. This leads, ultimately, to the failure of the specimens through repeated bending.

To produce the desired force these systems use commercial shaker units. These generate force along an axis by the interaction of the magnetic field surrounding a coil carrying an electrical current and that of a permanent magnet. This is the same method used in loudspeakers to create variations in air pressure using an electrical current.

These machines are unique because:-

- they were designed specifically to test small specimens and without the need for hydraulic fittings.

- specimens are tested without having to be gripped. Many materials, and especially fibre composite materials, are particularly susceptible to damage caused by applied pressure at grip points which could invalidate the test results.

- the load applied to the specimens (set by the user) is sensed by load cells and is accurately controlled right up to the time when the specimen fatigues catastrophically.

One of the two machines incorporates modifications to allow testing to be performed at elevated temperatures up to about 300 degrees Celsius.

Contents

1. Introduction

An important attribute of any new material intended for use in the aerospace industry is its response to cyclic stress. Unfortunately, new materials are usually in scarce supply or may be prohibitively expensive, so that testing must be carried out on very small samples. Gripping is often a problem as well, especially for fibre-reinforced composites. Under these constraints information about fatigue behaviour is most easily gathered by repeated bending. At AMRL [2] two bending-fatigue machines (Mk I, Mk II) powered by commercial electromagnetic shakers have been designed and built. This report describes the principles, circuitry and operation of these devices.

2. General Description

An electromagnetic shaker controlled with an electronic feedback system is used to apply cyclic loads to small (100 mm x 4 mm x 2 mm) test specimens. The specimens are held in either three or four point bending and cyclic loads up to 196 N (nominal) are then applied for a set number of cycles or until failure of the specimen. The load range (span) is set by the user and thereafter is held fixed with a closed loop feedback system.

3. The System

The complete system consists of a shaker unit, support structure, blower unit, hot air gun, and control system and is shown in Appendix 1.

3.1. Electromagnetic Shaker and Blower [3]

The shaker functions on the same principle as a moving coil loudspeaker. It uses a coil winding and magnet arrangement to develop an axial load of up to 196 N (nominal) at a maximum allowed root-mean-square (RMS) shaker coil current of 6.5A RMS. It has a maximum displacement (stroke) of 8.8mm and the manufacturer specifies a useful frequency range of DC-9kHz.

[2] Aeronautical and Maritime Research Laboratory (formerly Aeronautical Research Laboratory).

[3] Ling Dynamic Systems. Model 409.

The shaker is cooled with a blower unit which maintains a steady air flow around the armature assembly. The blower is mains powered from a switched outlet on the shaker power amplifier. The amplifier, therefore, provides both the drive current to the shaker and power to the blower.

3.2. Supporting Frame

The frame provides a stiff support for the test specimen and load cell. It also incorporates a damped flexure system to minimise the effects of mechanical resonances and to stiffen the shaker to off axis loads. Load is applied to the test specimen via one (three point loading) or two pins (four point loading) mounted on the shaft of the shaker and mechanical preload is applied with a thumbscrew and coil spring assembly (A1.5).

3.3. Function Generator

A function generator [4] provides the COMMAND signal which defines the load waveform to be applied to a specimen. The actual load is continuously monitored using a load cell and corrected to match the COMMAND waveform via the feedback loop. Since the COMMAND signal sets the desired load amplitude and form it must exhibit low noise and high stability for prolonged periods.

3.4. Load Cell Amplifier

This unit amplifies the millivolt level load cell signal and provides the DC excitation (10V nominal) needed for the load cell. This is a very low noise amplifier which includes DC offset (bridge balance) and gain controls. The offset control enables the amplifier's output to be nulled when static loads are present and the gain control compensates for cells with different sensitivities. The output is referred to in this document as the FEEDBACK signal.

This unit was designed and built at AMRL but was modified by the author for this specific application. See Appendix 2 and Appendix 3 for details.

3.5. AMRL Servoamplifier

The servoamplifier electronically sums two signals - COMMAND and FEEDBACK - to produce an ERROR signal which, via the power amplifier, controls the displacement

[4] Stanford Research Systems. Model DS345.

of the shaker to give the desired load. Some signal conditioning is provided internally and there are gain, stability and slew rate controls.

The servo control electronics are described in a separate report (Technical Memorandum AR-004-013, Structures Division, 1985) except for changes made by the author which are detailed in Appendix 3.

The servo loop gain has been lowered from the original AMRL unit since in this application the servoamplifier is driving a power amplifier instead of a hydraulic valve. The maximum voltage that may be delivered to the input of this amplifier is about 3.0 volt (~1V RMS) for full power out (~500 VA into a 5ohm load).

3.6. Power Amplifier

This amplifier [1-3] provides the current necessary to drive the shaker unit. It can deliver up to about 10A RMS continuous current into a load impedance of 5 ohm with very low distortion levels (<0.1%). A circuit monitors the output of the amplifier (refer 'Shaker Coil Protection', p.11) to protect the shaker from possible damage in case of a fault. A mains outlet on the amplifier is provided to power the blower unit and a current meter gives the current into the shaker unit via the output terminals. Figure A1.7 shows the internal layout.

3.7. Load Monitor

This converts the amplified load cell voltage from the load cell into two distinct DC output voltages one of which represents the mean level of the signal and the other its range or SPAN ie. the magnitude of the voltage difference between the peaks. The load monitor was designed and built by the author.

3.8. Divider and Cycle Counter

The cycle counter logs cycles to failure and the divider circuit ensures that the counter does not overrun during a test. The divider circuit transforms the load signal into a TTL compatible square wave after which it is divided by 16 (Mk II) or 256 (Mk I) and passed on to the cycle counter. A microswitch on the loading frame is set to trip at the instant of specimen failure and inhibits further counting.

3.9. Muting Circuit

This circuit allows the operator to disable the shaker at any time during a test without terminating load abruptly, as would be the case with a simple on/off switch. This method offers the advantage that mechanical stresses are significantly reduced on both the shaker and the specimen. It also means that a test can be halted and restarted at any time without damaging the specimen.

Muting is achieved by actively ramping the ERROR signal (which drives the power amplifier) over several seconds from the time the operator activates the circuit. Conversely, when restarting a load sequence the mute circuit slowly ramps up the ERROR signal. Designed and built by the author. Refer to Appendix 3 for details.

4. Signal Monitoring

4.1. COMMAND

The COMMAND signal provides the waveform and sets the amplitude of the desired load profile. It may be either a simple cyclic waveform or an arbitrary spectrum. The source of this signal should be a good quality function generator.

4.2. FEEDBACK and ERROR

The FEEDBACK signal is the amplified load cell output and is a measure of the actual load on the test specimen. Ideally this signal should replicate exactly the COMMAND signal since this represents the desired load shape and in general, during fatigue testing, this signal should be monitored continuously on a Cathode Ray Oscilloscope (CRO). Problems associated with the electronics or mechanical alignment will appear as a distortion of this waveform when compared with the COMMAND signal.

The ERROR signal is a measure of the deviation between the desired load and the load actually experienced by the specimen at any given time.

Test points are provided for monitoring the ERROR and FEEDBACK signals. Instruments such as voltmeters, oscilloscopes etc. can be connected at these points without the risk of affecting the operation of the servoamplifier or the feedback loop. The test points have been brought out to the front panel of the servoamplifier [5].

4.3. Load Monitor

This circuit processes the load on the specimen and displays it on two digital panel meters as:-

(1) the peak-peak (SPAN) value of the load as sensed by the load cell.

(2) the mean (actually the median) load

These are also provided as DC voltages on appropriately labelled BNC connectors at the front of the unit. The maximum peak-peak output voltage is 15 volt and +/- 7.5 volt for the mean.

The SPAN is a differential signal and should not, therefore, be connected to any instrument whose input is referenced to ground. This is not the case for the mean output. Shown below are the outputs for a typical input signal. The useful frequency range of the load monitor is from about 3 Hertz (Hz) to several kilohertz (kHz). Below about 3Hz, the output will have significant ripple which reduces the accuracy of the readings. The mean and SPAN outputs from this instrument are accurate for non-sinusoidal signals without requiring re-calibration.

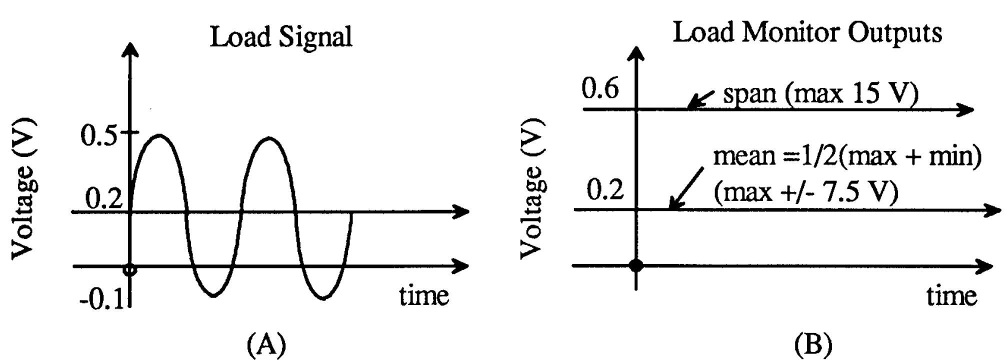


Figure 1: Load monitor outputs for a typical sinusoidal input voltage.

Because of the need to work at very low frequencies (ie. <~10 Hz) the output response time of the instrument (SPAN and mean outputs) to signals which are decaying is necessarily slow, although the response to an increasing load is relatively fast. The approximate time response of the outputs for a step input is shown in figure 2, below.

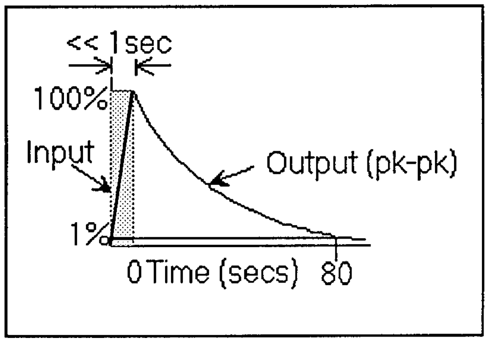


Figure 2: Load monitor response to a step input load signal. The shaded area represents the input load and the solid line is the response. The monitor's slow characteristic helps smooth fluctuations in low frequency signals.

For faster readings, of reducing signals in particular, the monitor is equipped with a reset switch which causes the monitor to update the meters to the current state of the load signal within about 1 second.

4.4. Distortion

Sometimes the load waveform can become distorted due to either mechanical misalignment of the shaker or excessive DC voltage in the feedback system. Any noticeable distortion will reduce the ability of the system to produce a desired load.

Mechanical misalignment can and should be corrected by following the manufacturer's alignment procedures.

DC voltages (offsets) in the feedback system are normal and, provided the offsets are small compared with the applied loads, the overall accuracy of the system will not be adversely affected. Excessive offset voltages can, however, cause distortion and must then be reduced. The servo amplifier has a potentiometer control labelled SET POINT which simulates the effect of applying a static mechanical load by inserting a DC voltage into the servo loop.

POINT which simulates the effect of applying a static mechanical load by inserting a DC voltage into the servo loop.

The SET POINT control is normally used at the start of a fatigue test to zero offsets caused by mechanical preload. Readjustment may be required occasionally during a prolonged fatigue test since the mean load and, hence, the mean signal level may vary according to the condition of the test specimen. The mean signal, as indicated on the front panel of the servo amplifier, should be set to within +/- 15 of the zero position.

5. Load Control

5.1. Span Load

The control system maintains a constant span (peak-peak load) as seen by the load cell. The precision to which this is achieved is affected by many factors including the servo gain setting, stability of the load cell and COMMAND signal and the servo electronics. In normal operation the variation in the SPAN for the duration of a test (several days) will be of order 1%.

5.2. Mean Load

The mean load varies only very slowly during a test and, although monitored, is not controlled by the servo system. This is deliberate and has been facilitated by modifying the power amplifier to amplify only AC signals greater than about 2Hz.

This approach lessens the risk of inadvertently applying a DC overload to the shaker unit in the event of a mistake by the operator or an electronic failure. If it becomes necessary to also control the mean load this can be readily achieved, details for which are given in Appendix 3.

6. Mains Filtering

To reduce the effect of mains noise a four outlet filtered power board [5], is used to distribute power to the function generator, load cell, servoamplifier and load monitor. The power amplifier is connected directly to the unfiltered mains since its design is inherently insensitive to mains noise.

[5] Squeaky Clean Mains Filter. Jaycar Electronics. Melbourne. Cat. MS-4020

A no-volt release [6] switch has been placed in series with the mains supply. In the event of a power interruption this switch will disable power to the system regardless of when the mains supply is restored. This helps avoid possible damage to the shaker and/or specimen during a power disturbance or outage. A reset switch allows the operator to restore power to the system manually.

8. Earthing

Each of the interconnecting electrical units is earthed internally but the metal frame of the support structure must be earthed independently.

Connect a heavy gauge earthing strap between the frame of the bending rig and any convenient earth (preferably the chassis of the power amplifier). This earthing arrangement prevents electrical noise, picked up by the metal frame, affecting the servo system.

9. The COMMAND Signal

Since the COMMAND signal provides the load waveform it must be stable over many days regardless of variations in parameters such as the mains supply voltage and laboratory temperature. It must also be as noise free as possible and, in order to achieve displacements of at least 4mm peak-peak, should be capable of up to about 4.0 volt peak-peak. With this voltage range the maximum current/amplitude that can be applied to the shaker (at ~10Hz) should span the limits stated by the manufacturer ie. 6.5A. Digital signal generators, because of their inherently high stability, are the preferred means for generating this signal.

The amplitude can be controlled from either the signal source (ie. the function generator) or by a combination of the signal source and the SPAN control on the servo amplifier front panel. The SPAN control is simply an attenuator for the COMMAND signal.

[6] Radiospares Pty Ltd. Stock No. 340 - 049. 52 Derby St., Tullamarine 3053

10. Frequency Limits

10.1. Maximum Frequency

For a given amplitude of the COMMAND signal, as the COMMAND frequency is raised, the displacement of the test specimen diminishes due to mechanical latency. Consequently, for any given frequency, there is an upper limit to the load that can be applied. For a given load there is then a definite maximum frequency for testing in the absence of other restrictions.

Induced resonances in the rig and benchtop, particularly at higher frequencies, may also limit the practical working frequency. Other possible limitations are the response of the servoamplifier and power amplifier although their performance should far exceed the inherent mechanical constraints.

As a guide we have found it possible to achieve a displacement of about 3.5 mm peak-peak at 50Hz in a boron fibre composite specimen (thickness 2mm) without apparent distress to the system. The useable frequency range may be higher than this.

10.2. Minimum Frequency

The lowest useable frequency is set by the high pass design of the power amplifier. The power amplifier low frequency cutoff (-3dB point) has been set to about 1.4Hz, and frequencies lower than about 2Hz will cause a protection circuit inside the power amplifier, to disconnect its output from the shaker. This circuit behaves like a resettable fuse and prevents possible damage to the shaker by very low frequency or DC currents.

In any event the load monitor circuit does not give stable readings below about **3Hz** so that the system should not be used below this frequency.

The low frequency response can be extended to DC by a modification to the power amplifier and by disabling the DC protector circuit (refer to Appendix 3). The servo system would then control the mean load as well as the load span.

11. Power Amplifier Warning Lamps

11.1. Clip

A red light emitting diode (LED) on the power amplifier front panel will light when the amplifier's output is close to saturation (clipping). This is only a warning device but it is useful in avoiding damage to the shaker. Illumination of the warning LED requires that the input signal amplitude be reduced until the LED is extinguished.

11.2. Rails OK

The power amplifier has two high current DC power rails (approx. + 80V, -80V) which supply current to the output stage of the amplifier and, finally, to the shaker. A green light emitting diode (LED) labelled RAILS OK will be lit when these supply rails are functioning normally. If either rail fails, power to the shaker coil is automatically cut.

Each rail has its own 10A fuse, labelled POS (+80 V) and NEG (-80 V) and if either fuse fails the RAILS OK LED will extinguish and the shaker protector circuit will activate.

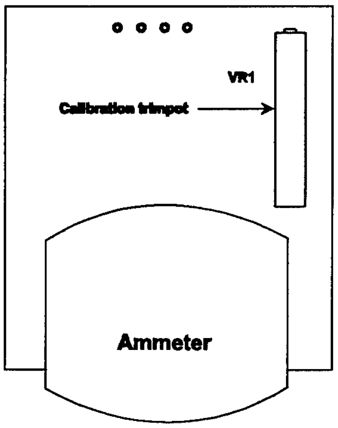
12. Shaker Coil Current

The power amplifier is capable of delivering more than the maximum permissible current for the shaker unit. For that reason it is provided with a current meter which designed to show the RMS current in the shaker coil. The meter, which is mounted on the power amplifier front panel, is calibrated for a sinusoidal waveform but a trimpot on the current meter circuit board (see figure 3) can be used to re-calibrate the meter for other cyclic waveforms.

12.1. Calibration

To calibrate the current meter connect a true RMS reading ammeter in series with a load of between 10 ohm to 15 ohm across the amplifier output. With the desired waveform across the load adjust the amplitude until the ammeter indicates a current of 4-6A. Adjust the calibration trimpot (VR1) until the amplifier ammeter matches the already measured RMS current. The dummy load will need to withstand the power involved (4A into 10 ohm =160W).

(A)



(B)

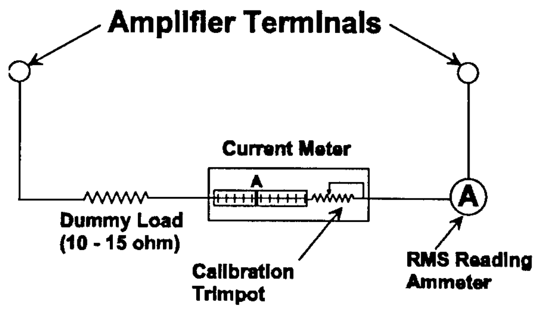


Figure 3: (A) Plan view of current meter circuit board showing trimpot for calibration.
(B) Circuit for calibrating the current meter.

13. Shaker Coil Protection

The shaker coil is protected against most overload conditions by a circuit which monitors the status of the power amplifier output and which uses a relay to disconnect the shaker in the event of a problem. The relay is triggered when:-

- A DC voltage develops at the amplifier output terminals. Because the amplifier is set to amplify AC only there should never be a DC voltage here unless a fault occurs. In practice, low frequency signals below about 2Hz or signals with a low frequency component can be interpreted by the monitor circuit as a fault and trigger the relay. The relay may operate, for example, when manually adjusting the BRIDGE BALANCE or SET POINT controls.

- There is a failure of one or both of the main DC power rails inside the amplifier.

When the 'fault' condition is removed the output is automatically restored to the shaker after a delay of about one second.

14. Transient Signals

Electrical transients or 'spikes' are short signal bursts and occur typically when electrical equipment is switched on or off. If a transient load is applied to a test specimen as the result of an electrical transient the specimen can be damaged or a test may be invalidated.

Aside from electrical noise on the electricity supply, transients can result from the way this equipment is used:-

- Switching off the power amplifier without first disabling the servo control will cause the system to react to the forced change in load. The power amplifier has enough stored energy for several seconds to produce a significant transient load at the specimen.

- Transients occur when the load cell amplifier and servo electronics are switched on or off and will be passed to the test specimen via the power amplifier if it is also on. Consequently the following sections describe appropriate methods for ensuring that specimen transients are avoided.

14.1. Avoiding Transients During Power-up

Transient loads at power-up can be eliminated by following the procedure shown below.

Set MUTE to OFF

↓

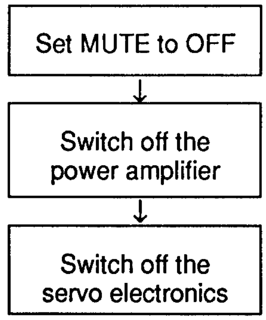
Apply power to servo electronics

↓

Apply power to the power amplifier

14.2. Avoiding Transients During Power-down

The power amplifier, of itself, can be switched on or off without affecting the shaker. However, this is not the case when the servoamplifier is also connected and the feedback loop is operating. When this is the case, as during normal operation, use the following procedure.



15. Standard Procedure

Figure 4 gives a simplified flow chart showing the routine steps involved in operating the shaker system.

15.1. Nulling Offsets

Before inserting a specimen and applying preload any offset voltages at the load cell amplifier output must be nulled. In that way zero applied load will correspond with zero output from the load cell amplifier and, when preload is later applied, the amount of preload can measured directly from the load monitor.

First ensure that there is no load bearing on the load cell. Disconnect the COMMAND signal and connect a voltmeter across the output of the load cell amplifier. Null the bridge by adjusting the BRIDGE BALANCE potentiometer on the front panel to give approximately zero volt (< +/- 5mV). Use a voltmeter or CRO to monitor the output of the load cell amplifier as you adjust the BRIDGE BALANCE potentiometer.

The servo amplifier must now be nulled. With the SET POINT potentiometer at the six o'clock position, monitor the ERROR signal on the servoamplifier and adjust the SET POINT control until the ERROR signal voltage is also approximately zero. The meter on the servo amplifier front panel can be used as a guide. The NULL LED on the servoamplifier should now be lit. The offset can be further reduced, if desired, by repeating the above procedure at a higher SERVO GAIN (see Servo Gain, p.17) setting.

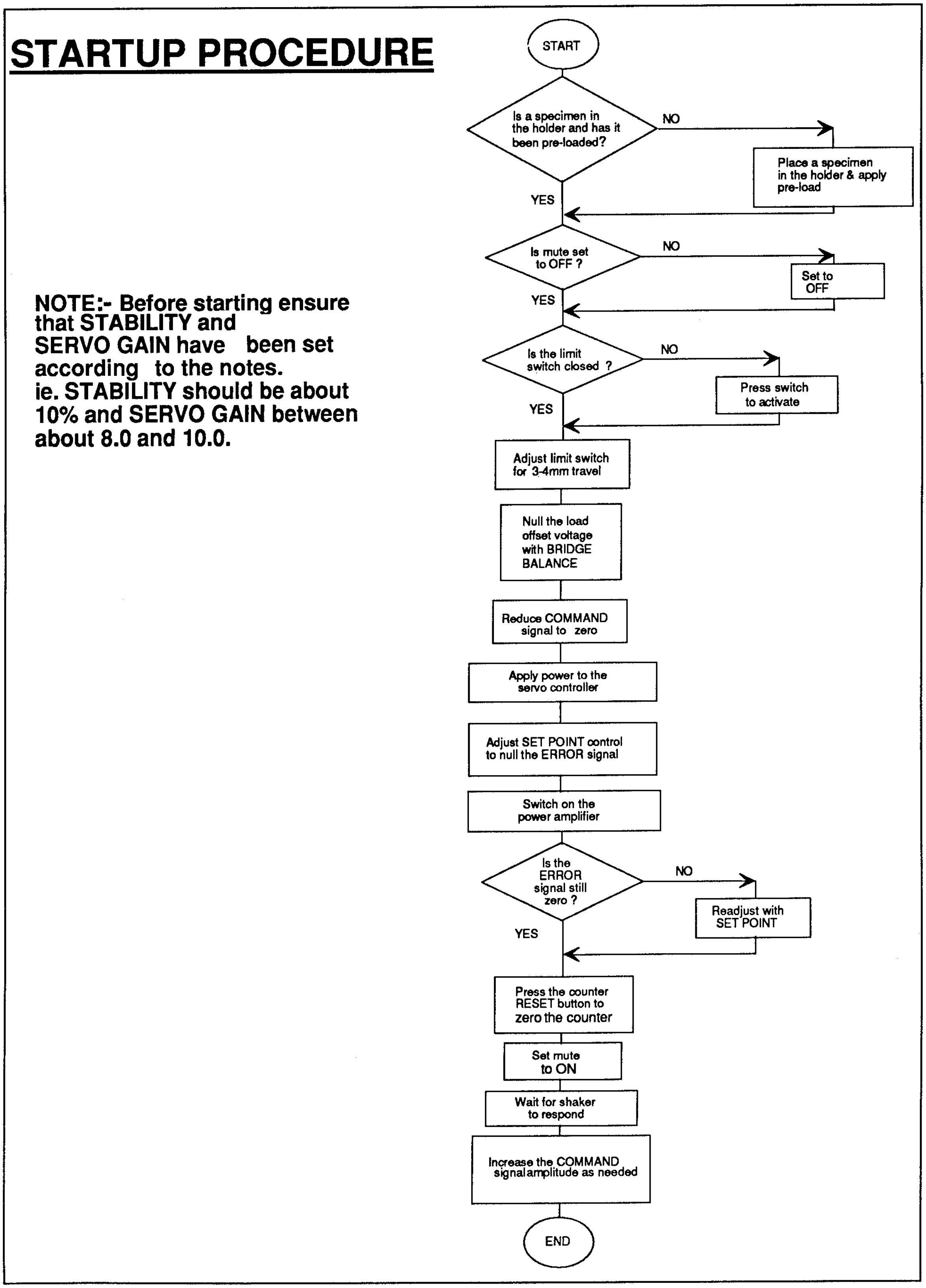


Figure 4: Standard operating procedure for the shaker system

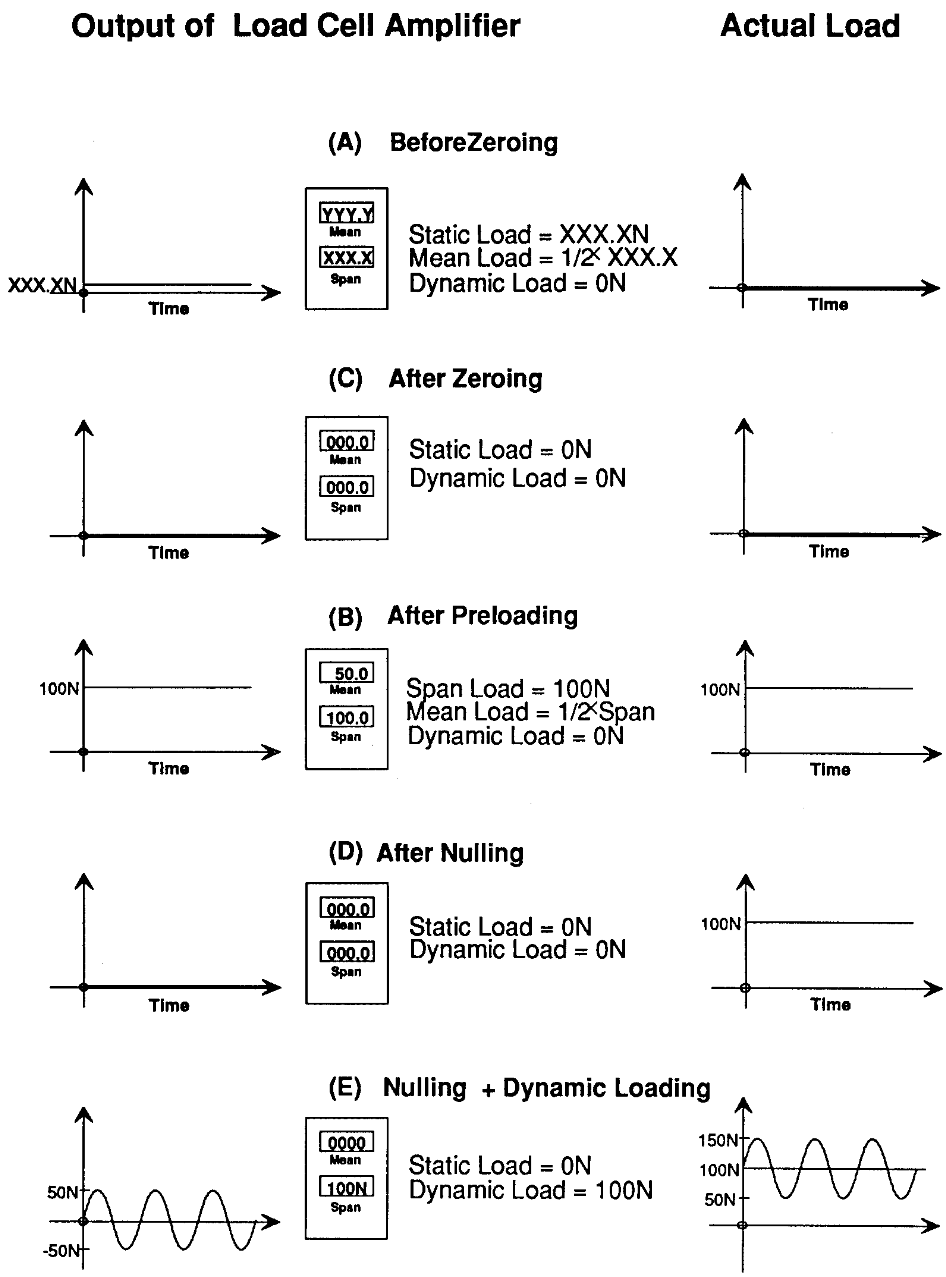


Figure 5: Load cell amplifier output and actural loads during setup

The null point should be reached with the SET POINT potentiometer at the six o'clock position. If it is more than a half turn from this position when the NULL LED is lit it will be necessary to rotate SET POINT back to the six o'clock position and readjust the NULL ZERO trimpot on the servoamplifier front panel until the NULL LED is lit.

At this stage it will be necessary to apply a static preload to the specimen.

16. Specimen Preload

Before applying cyclic bending loads each test specimen must first be mechanically preloaded. This ensures that at no point during a load cycle will the specimen become unloaded. A knurled thumbscrew and spring arrangement is provided on the loading frame for this purpose.

With offsets nulled as described in section 15.1, the preload will be displayed in units of Newton on the load monitor panel as SPAN load.

16.1. Nulling the Preload

Preloading produces a DC voltage at the load cell amplifier output and this offset must be nulled. Use the same procedure as described in 'Nulling Offsets', p. 13.

17. The Load Cell Amplifier

17.1. BRIDGE BALANCE

The load cell used in this system is of the Wheatstone Bridge configuration where strain gauges internal to the cell actually form the elements of the bridge. The BRIDGE BALANCE potentiometer is used to null the output from the bridge when, for example, a non zero preload exists.

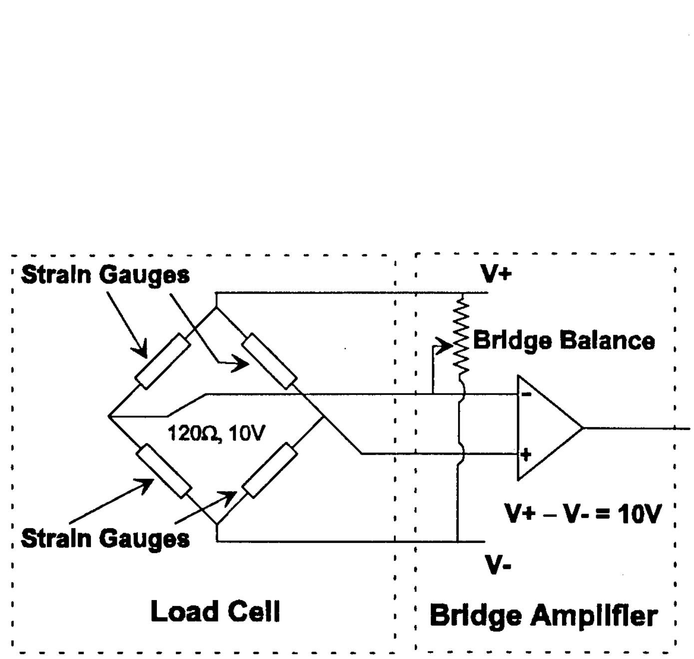


Figure 6: Load cell and bridge balance circuit

17.2. Bridge Gain and Offset

The load cell amplifier gain may be adjusted by a ten turn trimpot, labelled GAIN, which is accessible from the amplifier front panel. This control works in tandem with the FB GAIN potentiometer to set the overall feedback gain and the setting of the GAIN potentiometer is, of itself, not critical. Where the feedback gain requires adjustment [5], in most cases it should suffice to use only the FB GAIN potentiometer. However, when a load cell is replaced the GAIN control will have to be adjusted to compensate for any change in sensitivity. The control is set correctly when the load monitor panel meters read the correct load for that cell.

The offset control potentiometer, called BRIDGE BALANCE, on the load cell amplifier corrects for load cells which are out of balance, ie. have a non zero output. A bridge which is not nulled will produce an offset voltage that can adversely affect the servoamplifier and could trigger the protector circuit in the power amplifier, thus making the shaker inoperable. BRIDGE BALANCE must be used to null the bridge offsets caused by the preload or when the preload is altered as, for example, when a new specimen is used. Refer to 'Nulling Offsets', p.13 for details.

18. Servo Gain

The following is a guide to the correct method for setting up the servo system. Because of the different types of specimens and uses to which this system may be put, the following is intended only as a guide. More detail about the servo system can be found in TECH. MEMO AR-004-013 [5].

The SERVO GAIN control determines the overall gain of the feedback control system. With the SERVO GAIN set too high the servo loop becomes unstable, resulting in violent and uncontrolled oscillation of the shaker. Conversely, if the SERVO GAIN is set too low the servo system will exhibit poor load control. The optimal setting, therefore, is for the highest gain possible before the onset of instability.

Follow the general guidelines for commissioning the system (see Figure 4). Start with low or zero SERVO GAIN and steadily rotate the SERVO GAIN potentiometer clockwise until the onset of instability (uncontrolled mechanical oscillation) and then reduce this level just enough that the system becomes stable again.

18.1. The Load Monitor

The load monitor has adjustments for:-

(1) internal gain (VR3) and zero offset (VR1, VR2) for the SPAN output

(2) zero offset (VR4) and mean level (VR5) for the mean output.

To ensure accurate load readings these adjustments must be set in accordance with the following prescription and should be checked periodically to compensate for long term drift. The load monitor front panel is shown in Figure A1.8.

- Allow the equipment at least 30 minutes after powering up to stabilise.
- Before making any adjustments connect a 50Ω terminator or shorted BNC plug to the load monitor INPUT. This will ensure that stray signals do not interfere with the measurements.

18.2. Offset: Span

The load monitor circuitry is split into two symmetrical sections each of which must be nulled separately. There is, however, some interaction of the two circuits so that this adjustment is most easily accomplished using two voltmeters simultaneously. Connect one multimeter between the outer conductor of the BNC labelled SPAN and ground and the second multimeter between ground and the inner conductor. Adjust VR1 and VR2 in turn until both multimeters read less than about 1mV.

18.3. Offset: Mean

Connect a multimeter between ground and the inner conductor of the BNC labelled MEAN. Adjust VR4 until the voltage is less than about 1mV or until the panel meter for the mean load reads 0.00.

18.4. Mean Trim

This potentiometer is used to set the mean level output so that it accurately represents 1/2 (max + min) of the measured signal.

The adjustment is made by applying a constant voltage at the BNC connector labelled INPUT and setting the MEAN TRIM potentiometer, VR5, until the measured voltage equals 1/4 of the applied voltage.

18.5. Gain

The gain setting determines the output scaling for both MEAN and SPAN in Volt/Newton and is set by the single potentiometer, VR3. The gain setting is not critical, but as a guide the gain should be set so that when the shaker current is at the rated maximum (6.5A) the span load should give just less than about 10V. This is the preferred setting as it is convenient for most data logging equipment. The load monitor is now correctly adjusted.

19. Thermal Stability

To achieve <1% drift in the control system it should be allowed at least 30 minutes from power up to stabilise. While the system is stabilising the shaker should be made to do some work by, for example, cycling a 'dummy' specimen at a relatively small amplitude (current ~0.5A). This will reduce the time needed for the shaker assembly to reach thermal and mechanical equilibrium.

20. Load Calibration

The meters must be calibrated so that they give an accurate reading of the actual load applied to a specimen. The loading rig [7] is shown in figure A1.6 and consists of a T-shaped support, metal guide wire and pulley assembly. Accurately known weights up to 200N are hung from one end of the wire which passes over the pulley assembly to the shaker spindle where the load is transferred to the specimen via a three or four point bending fitment. The arm can be manoeuvred to align the guide wire with the vertical axis of the shaker.

To calibrate the panel meters so that they display load in Newton, attach a 200N dead weight to the loading rig and adjust the trimpots on each of the SPAN and mean circuit boards to read 199.9N and 100.0N respectively. The accuracy to which these can be set is limited in practice by several factors, including the ambient electronic noise and may produce fluctuations of up to the equivalent of about 0.4N.

21. Resonances

As with all oscillating mechanical systems the shaker unit exhibits resonances at particular frequencies, and these should be avoided to achieve optimum performance. Since this system behaves like a damped oscillating spring in which the restoring force depends in part on the test specimen, the actual resonant frequencies will vary according to the actual experimental conditions and must, therefore, be determined experimentally.

As a guide, we have observed with undamaged aluminum/boron composite specimens a single principal resonance at 19Hz and multiples (harmonics) thereof. ie 38Hz, 57Hz....etc. The resonance at 19Hz is quite narrow at about +/- 1Hz and is seen as a distortion of the FEEDBACK signal (sinusoidal) at the output of the load cell amplifier. It should be noted that, although these resonances are distinct, they are not particularly severe (under load control) and do not lead to 'runaway' of the system. Instead, there is an overall reduction in performance and stability causing distortion of the load waveform.

Conservative use of the STABILITY potentiometer on or near a resonance can significantly reduce the effect of resonances for sinusoidal loads but at the expense of some distortion of the load envelope at all frequencies. A stability of 10%-20% works well in most circumstances.

[7] Made by Mr. Gordon Collins, Airframes and Engines Division.

22. Compensation

Compensation refers to the method for tailoring the electrical response of the servo system to match the response of the mechanical device being controlled (ie. the shaker). Due to the combination of mechanical inertia, resonances, restricted frequency response, damping and other nonlinearities the mechanical system will inevitably deviate from the desired load waveform. By compensating the servo system electrically we seek to minimise as many of these effects as possible. Details relating to the adjustment procedure are given in [4], a summary of which follows. Begin with the following settings:-

Slew Rate	XX
SET POINT	5.00
Stability	0%
Servo Gain	Fully counterclockwise(0%)

XX Don't care

Set the function generator to about 8Hz and square wave output. Set SPAN to give about 1mm peak-peak specimen displacement at the centre of the specimen while monitoring the load cell output on a CRO.

Increase the SERVO GAIN (by clockwise rotation) until the onset of instability (uncontrolled mechanical oscillation) and then reduce this level just enough that the system becomes stable again. This will now function as the servo gain until such time as settings or mechanical properties change. Now, while observing the load cell output on a CRO, adjust potentiometers RV2 and RV3 on the compensation card (inside the servoamplifier) to produce the best square wave envelope. It may also be necessary to experiment with the STABILITY control although it is recommended that you do not exceed about 10% for this control as it can cause noticeable distortion of the sine wave response. You should now be ready to begin. Set the required cycling amplitude using the SPAN control or by adjusting the COMMAND signal directly.

In principle each new specimen requires that the compensation be reset, although in practice this should be unnecessary.

The sinusoidal response of the servo system doesn't appear to be significantly affected by the compensation adjustment but should, nevertheless, be adjusted for optimum system performance.

23. Summary

This system has been tested at room temperature and is expected to be commissioned for elevated temperature work by June 1994. The prototype version of this system (Mk I), developed for room temperature work only, was commissioned in 1991 and has proven to be both robust and reliable, having completed more than $60 * 10^6$ cycles without failure.

Both units are expected to continue making valuable contributions to the materials testing programs in this division.

24. Acknowledgements

The author wishes to thank Mr. S.McK. Cousland for his encouragement, advice and support throughout this project.

Mr. M.D. Engellenner deserves special recognition for developing the mechanical hardware. Without his very high level of technical expertise and attention to detail this project could not have been accomplished.

This work developed out of an original concept by Dr. A.A. Baker (Research Leader, Airframes and Engines Division).

I would also like to thank Mr. G. Collins for constructing the loading rig, Mr. L. Lambrianidis for many valuable discussions, Dr. D. Arnott, and Dr. B. J. Wicks for help during the preparation of this report.

25. References

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2. Tilbrook, D. Australian Electronics Monthly. July 1986. "An 'Ultra-fidelity MOSFET Power Amplifier Module. Part 2".
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6. Horowitz, P. and Hill, W. The Art of Electronics. Cambridge University Press. 1987.

7. Daniel H. Sheingold. Transducer Interfacing Handbook. A Guide to Analog Signal Conditioning. Analog Devices Inc. Norwood, Massachusetts 02062, U.S.A.

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Appendix 1: System

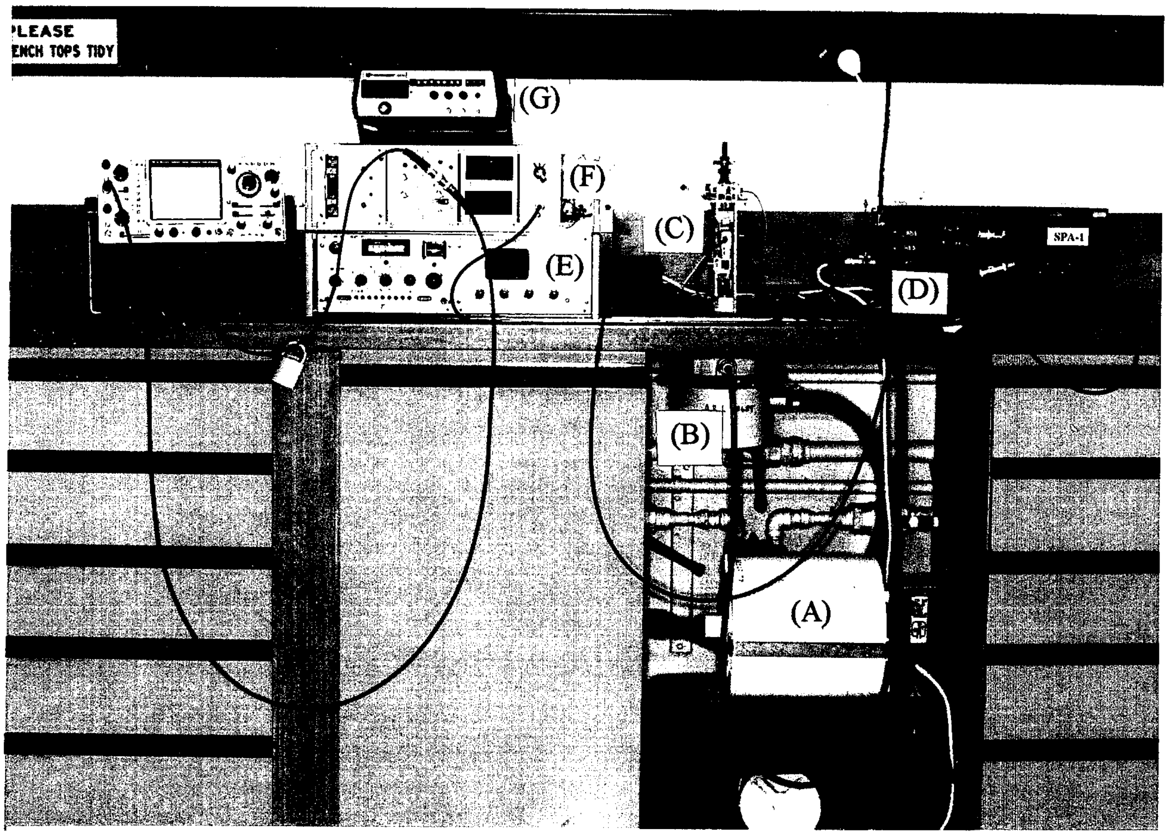

Figure A1.1: Shaker system Mk I. This version was designed for room temperature testing only.
(A) Blower. (B) Shaker. (C) Fatigue rig. (D) Power amplifier (SPA-1). (E) Servoamplifier (left) and cycle counter (right). (F) Left to right. Bridge amplifier, load monitors, load meters, and mute switch. (G) Function generator (COMMAND).

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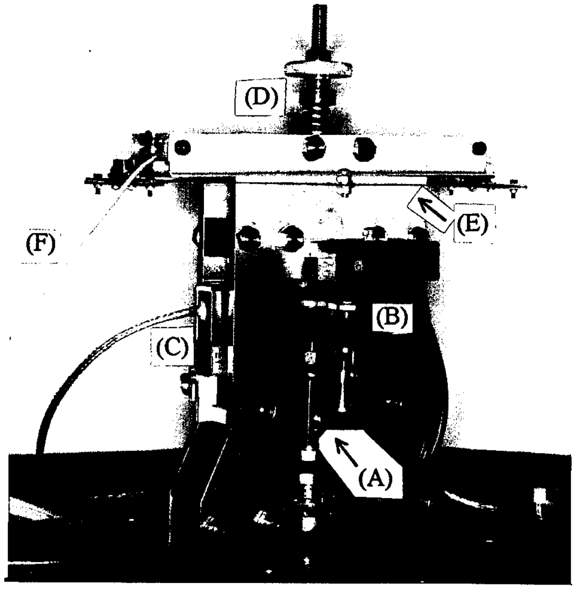


Figure A1.2: Fatigue rig Mk I (room temperature).
(A) Loading pin. (B) Limit switch. (C) Load cell. (D) Preload adjuster. (E) Damper. (F) Earth strap.

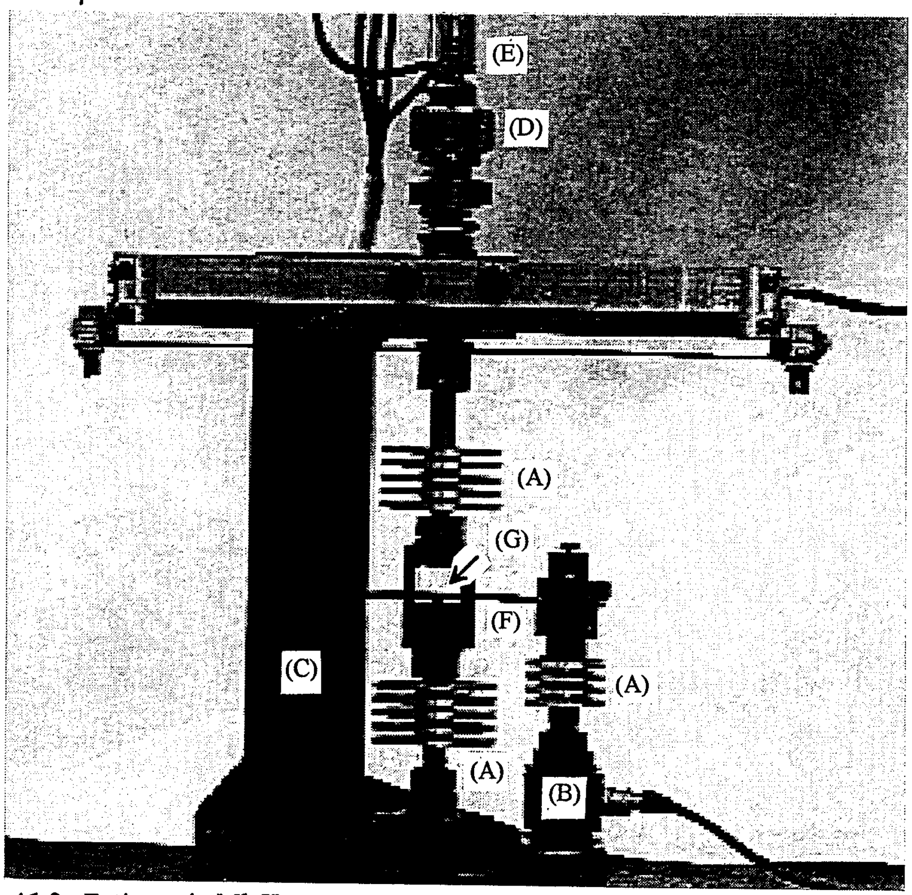


Figure A1.3: Fatigue rig Mk II.
(A) Cooling vanes. (B) Load cell. (C) Support frame. (D) Preload adjuster. (E) Limit switch. (F) Test specimen. (G) Loading pin.

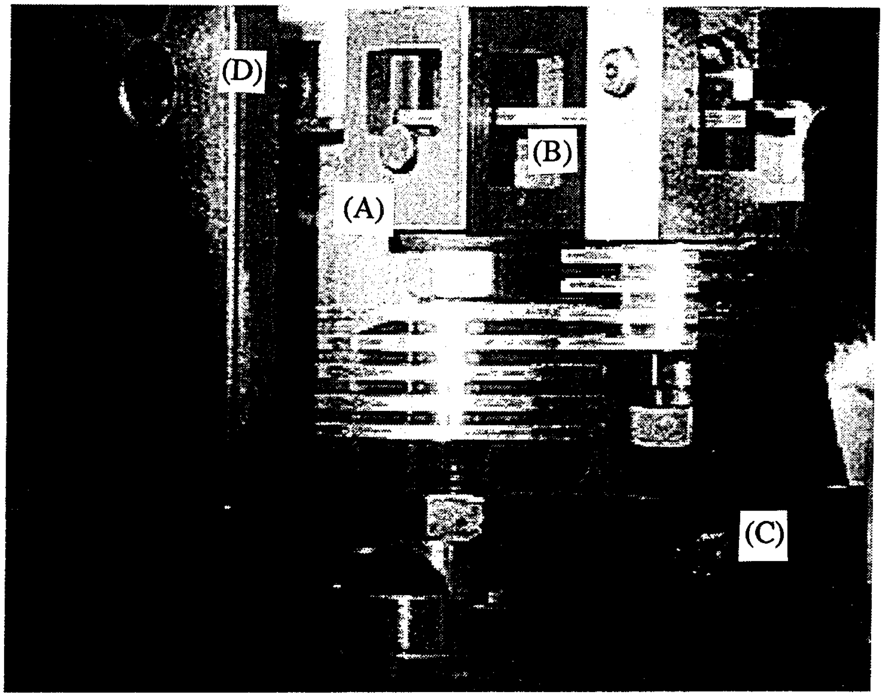


Figure A1.4: Detail of specimen and holder assembly. (A) Loading pin. (B) Specimen. (C) Load cell. (D) Roller.

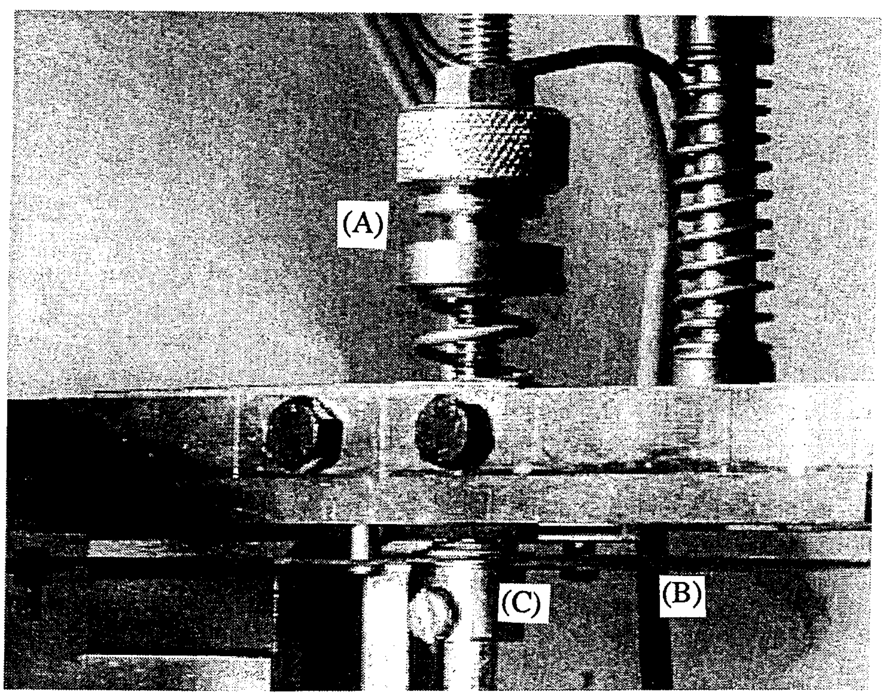


Figure A1.5: Detail of preload adjuster and damper.
(A) Spring tensioner. (B) Damper. (C) Collar connecting damper and shaft.

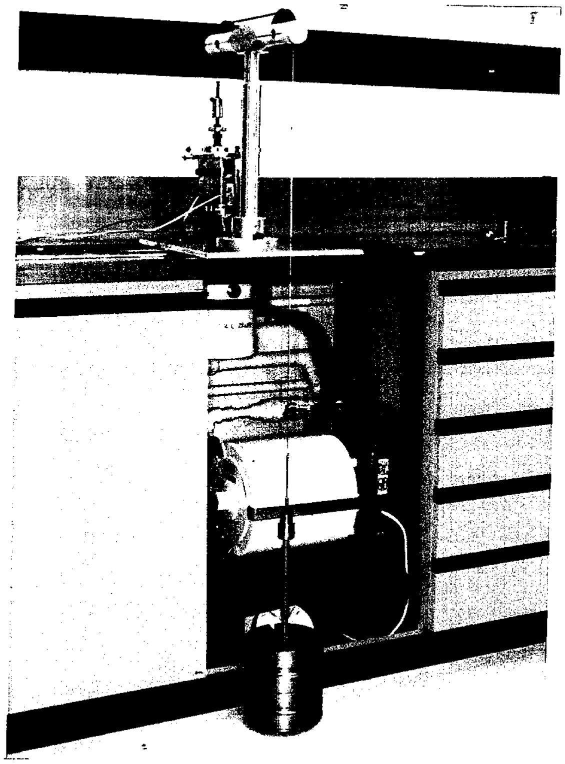


Figure A1.6: Loading rig in use with 200N dead weight.

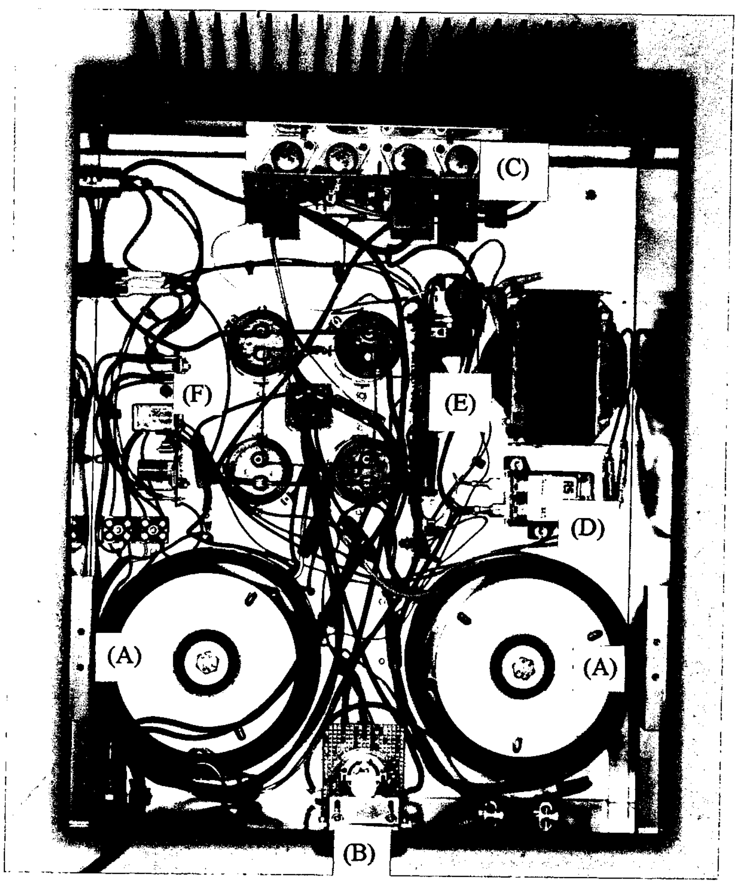


Figure A1.7: Power amplifier internal layout. (A) Toroidal transformers. (B) Current meter circuit. (C) MOSFET amplifier module. (D) Shaker protector relay. (E) Fault monitor circuit. (F) Surge limiter circuit.

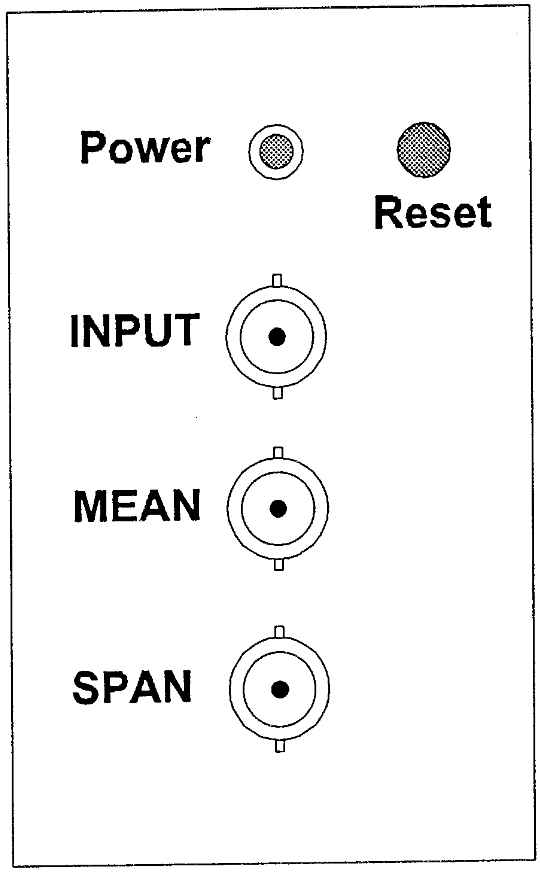
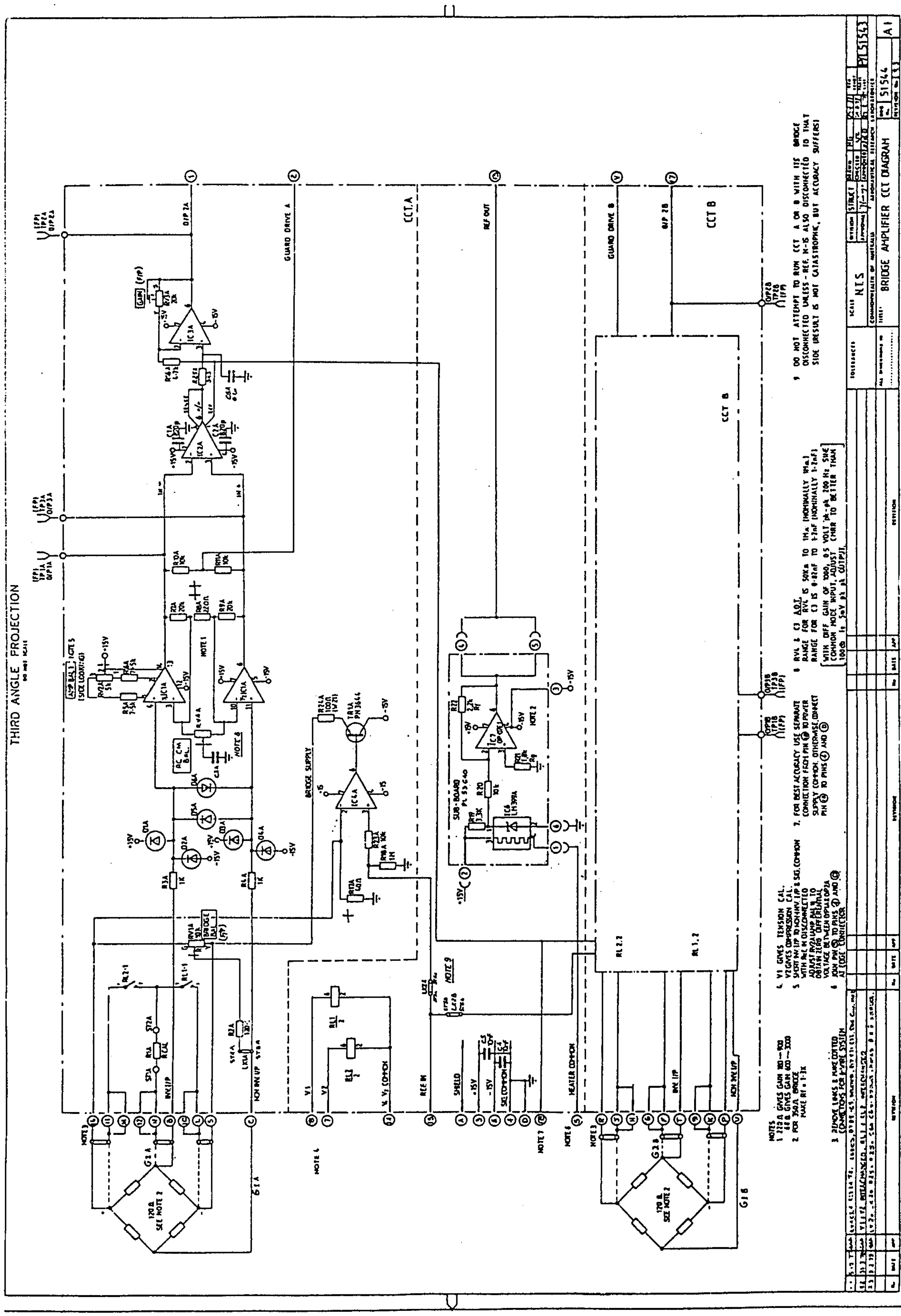
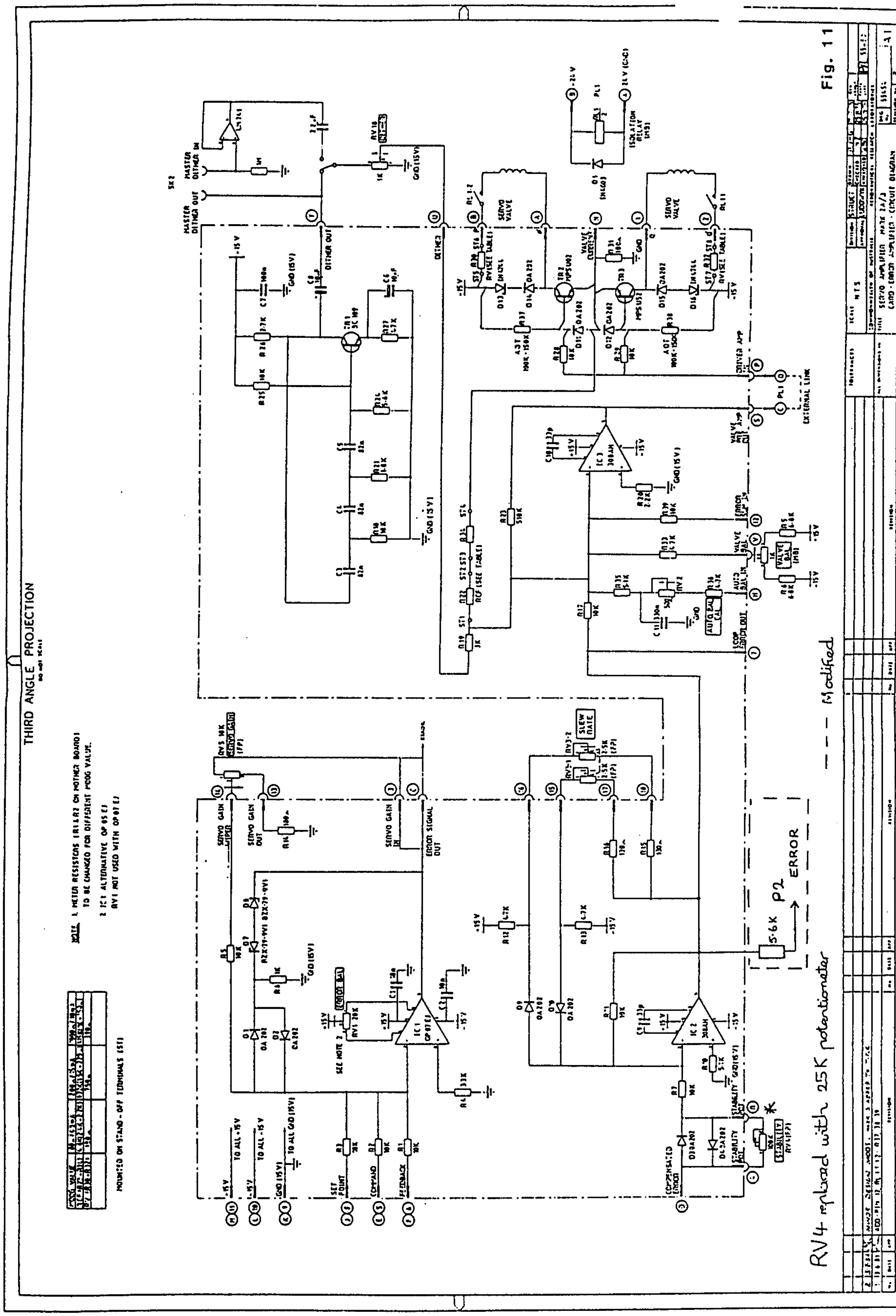


Figure A1.8: Load monitor front panel.

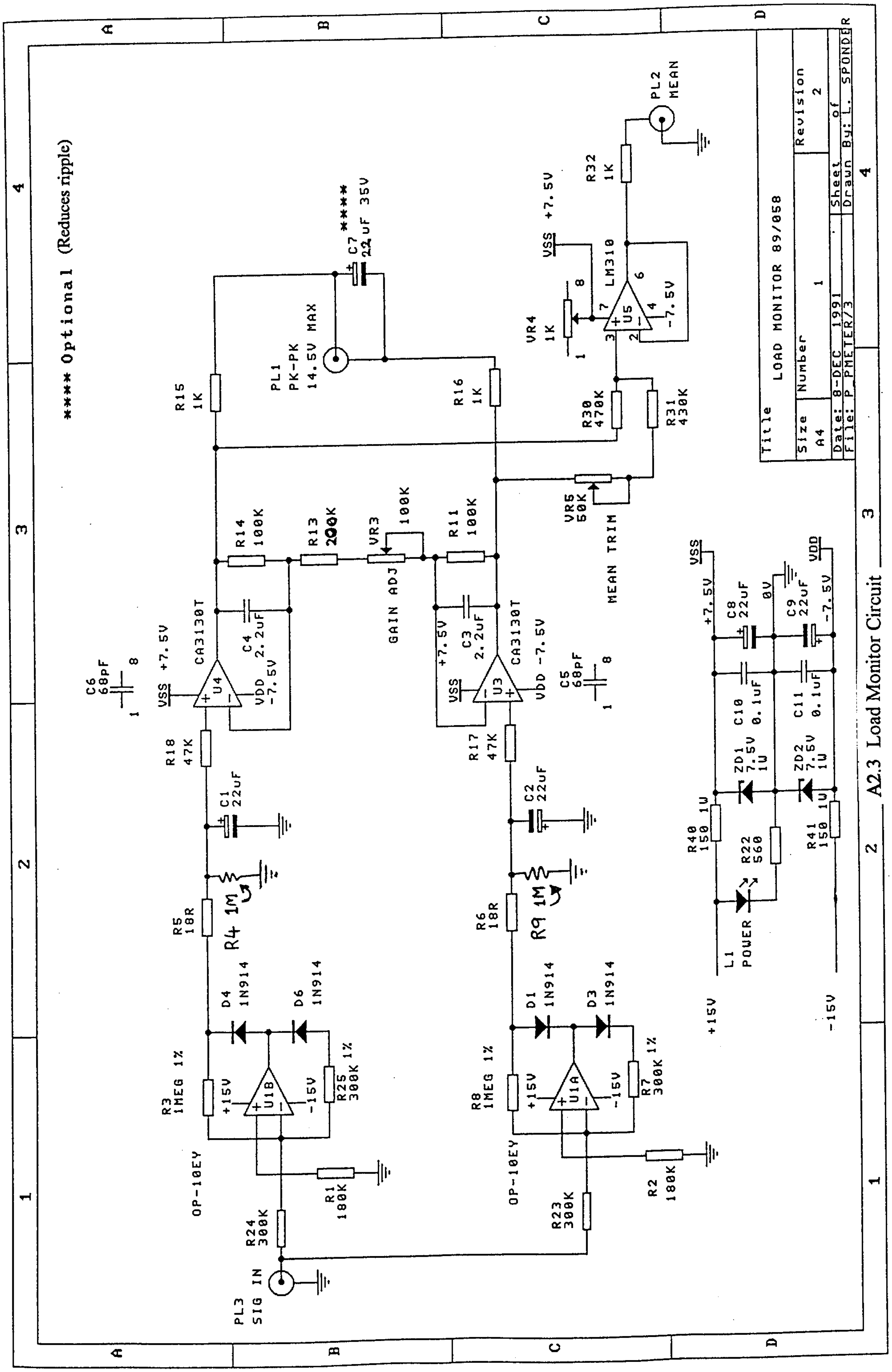
Appendix 2: Circuits and Drawings



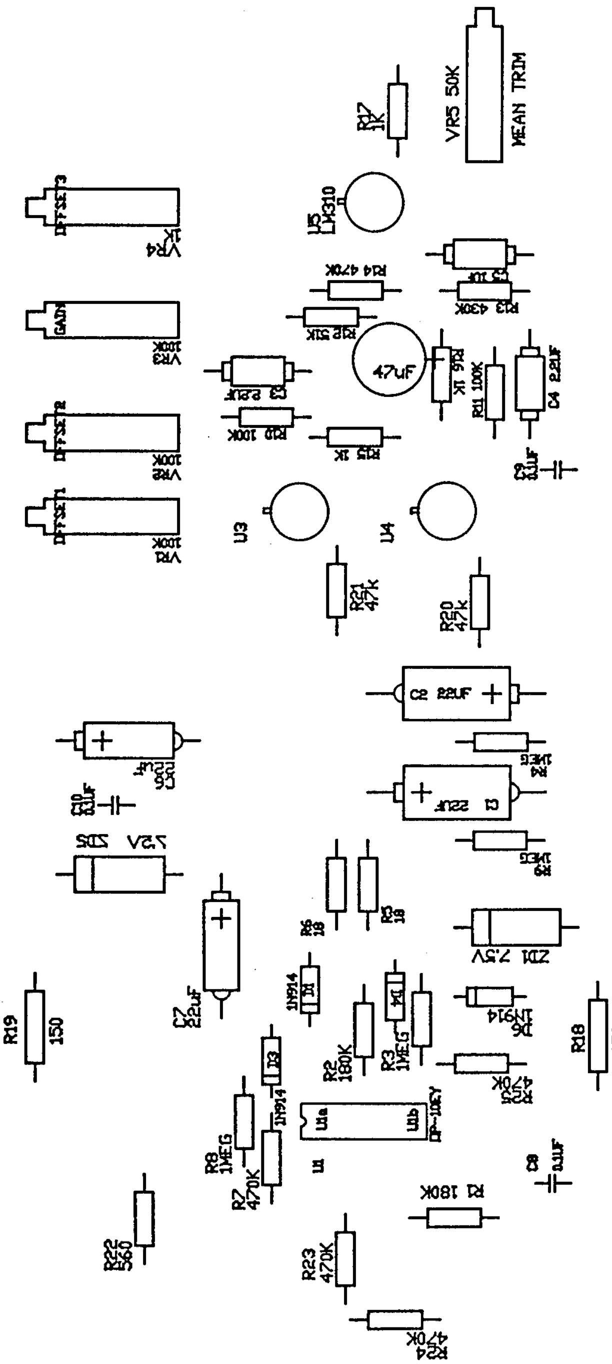
A2.1 Bridge Amplifier Circuit



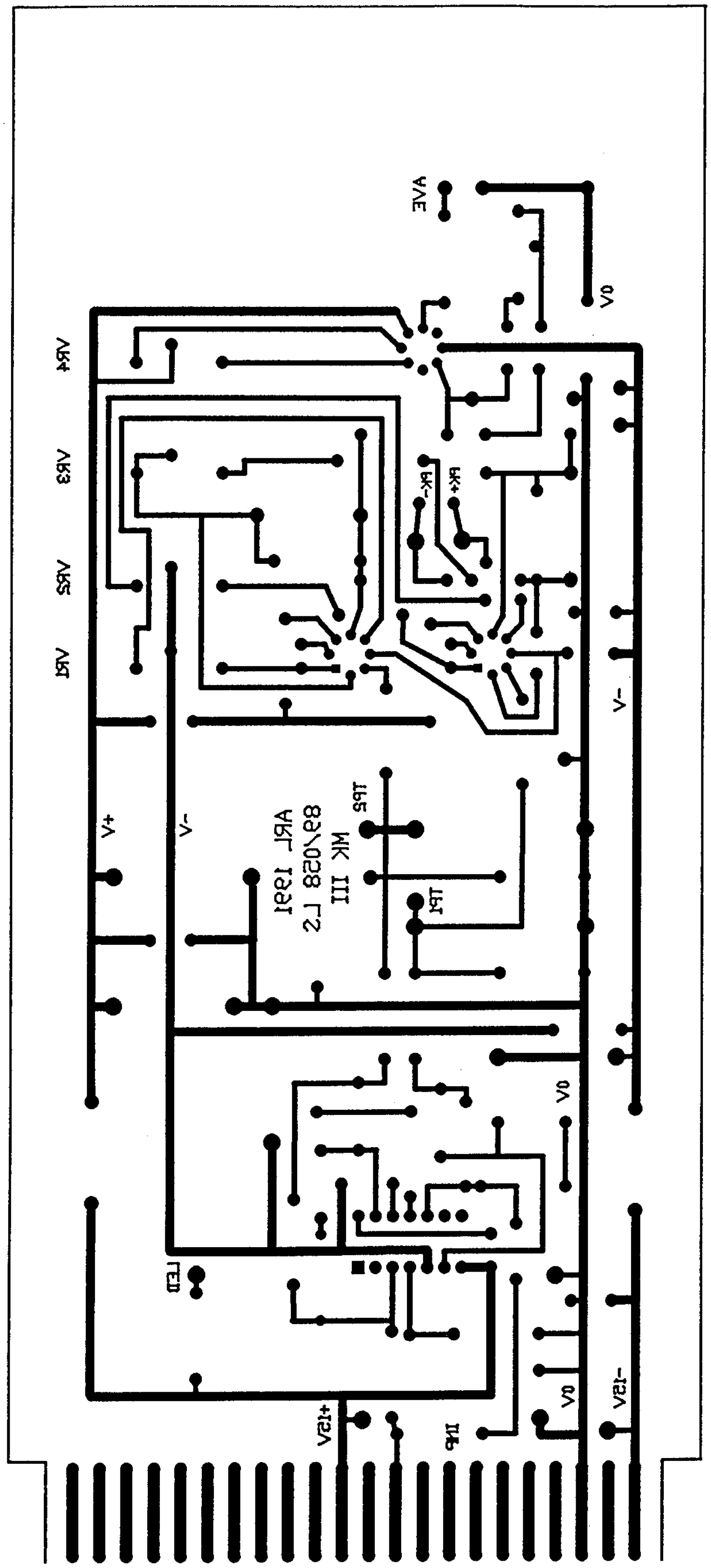
A2.2 Servoamplifier Circuit



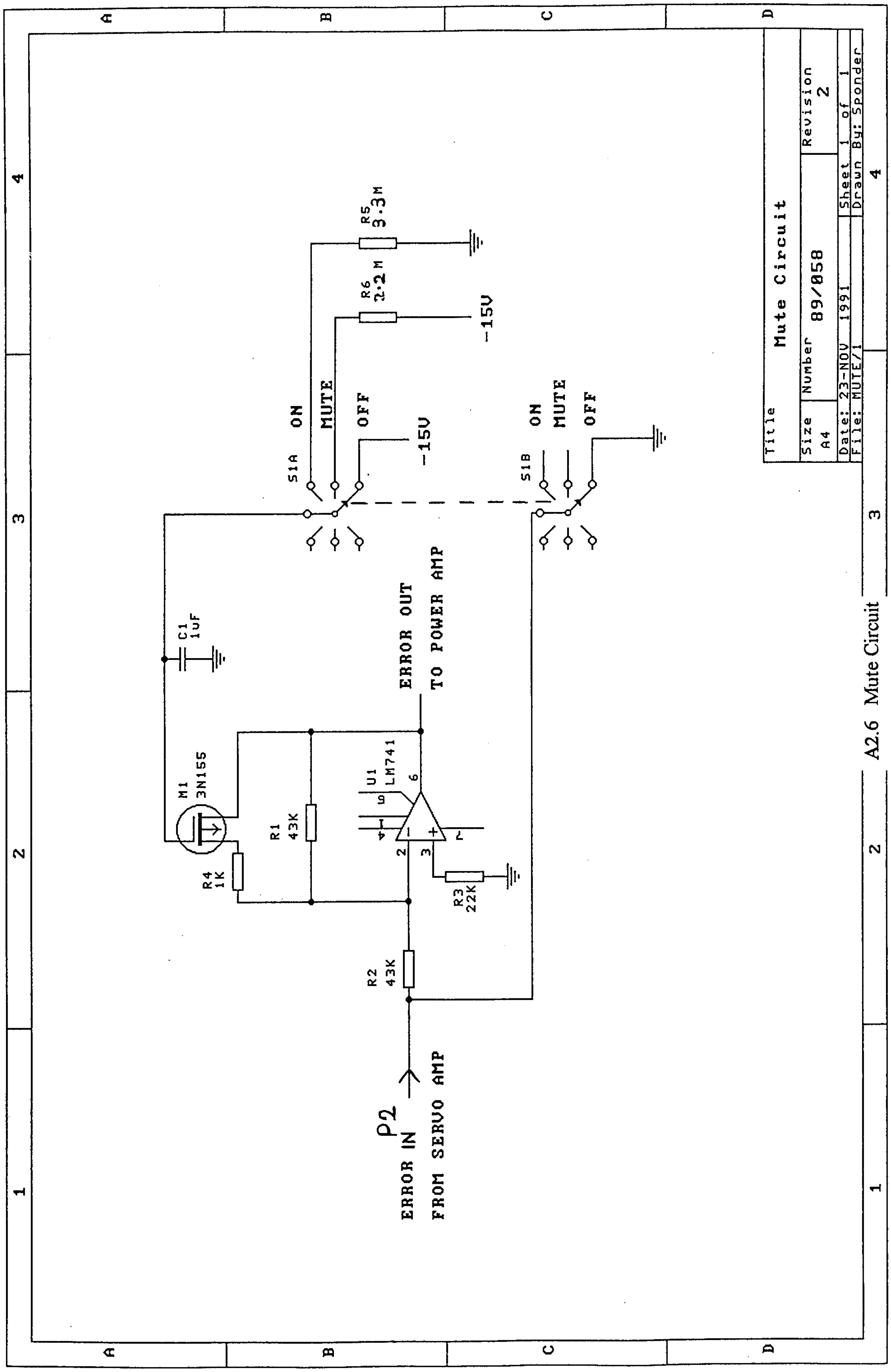
A2.3 Load Monitor Circuit



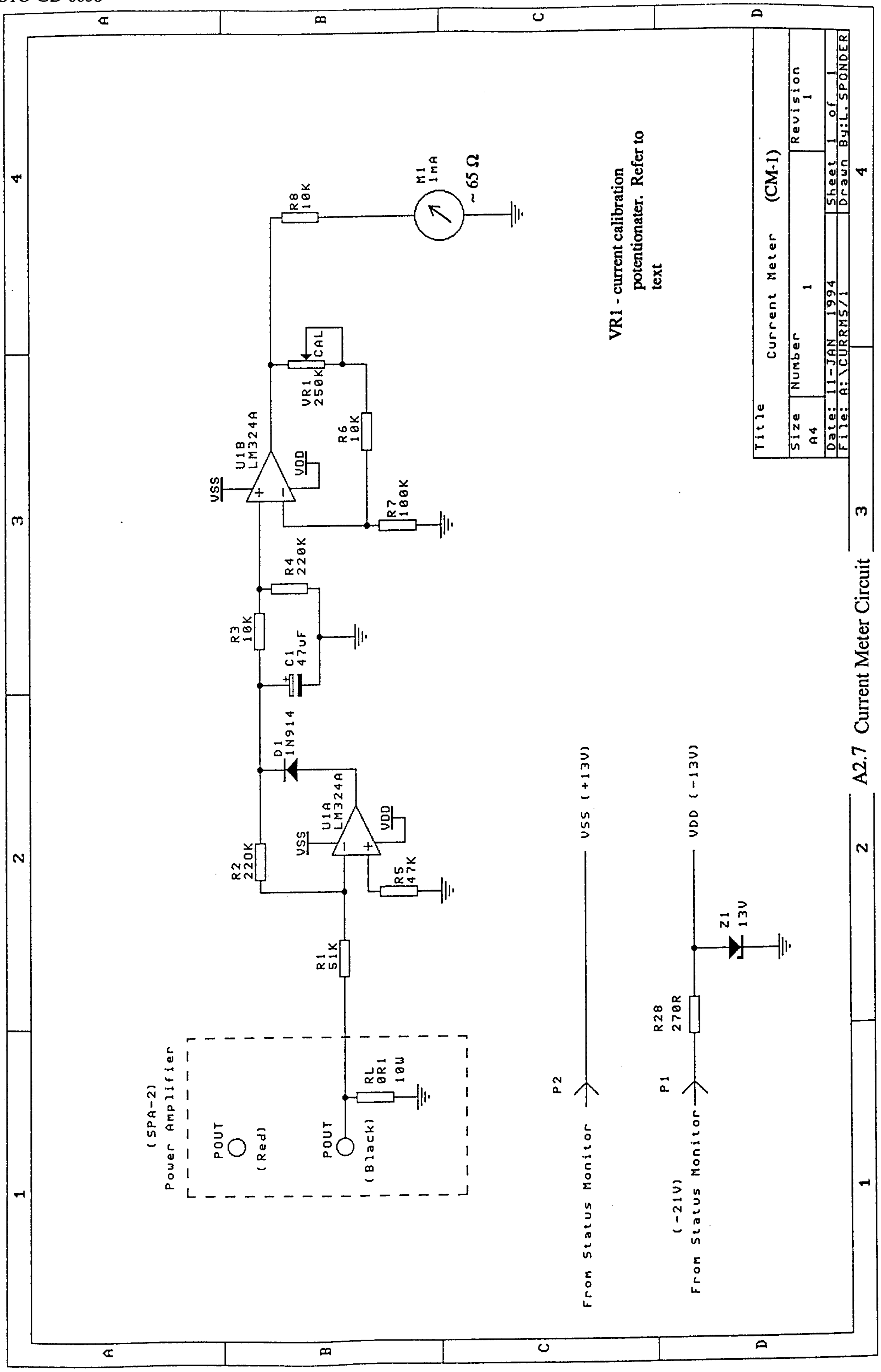
A2.4 Component Overlay for Load Monitor



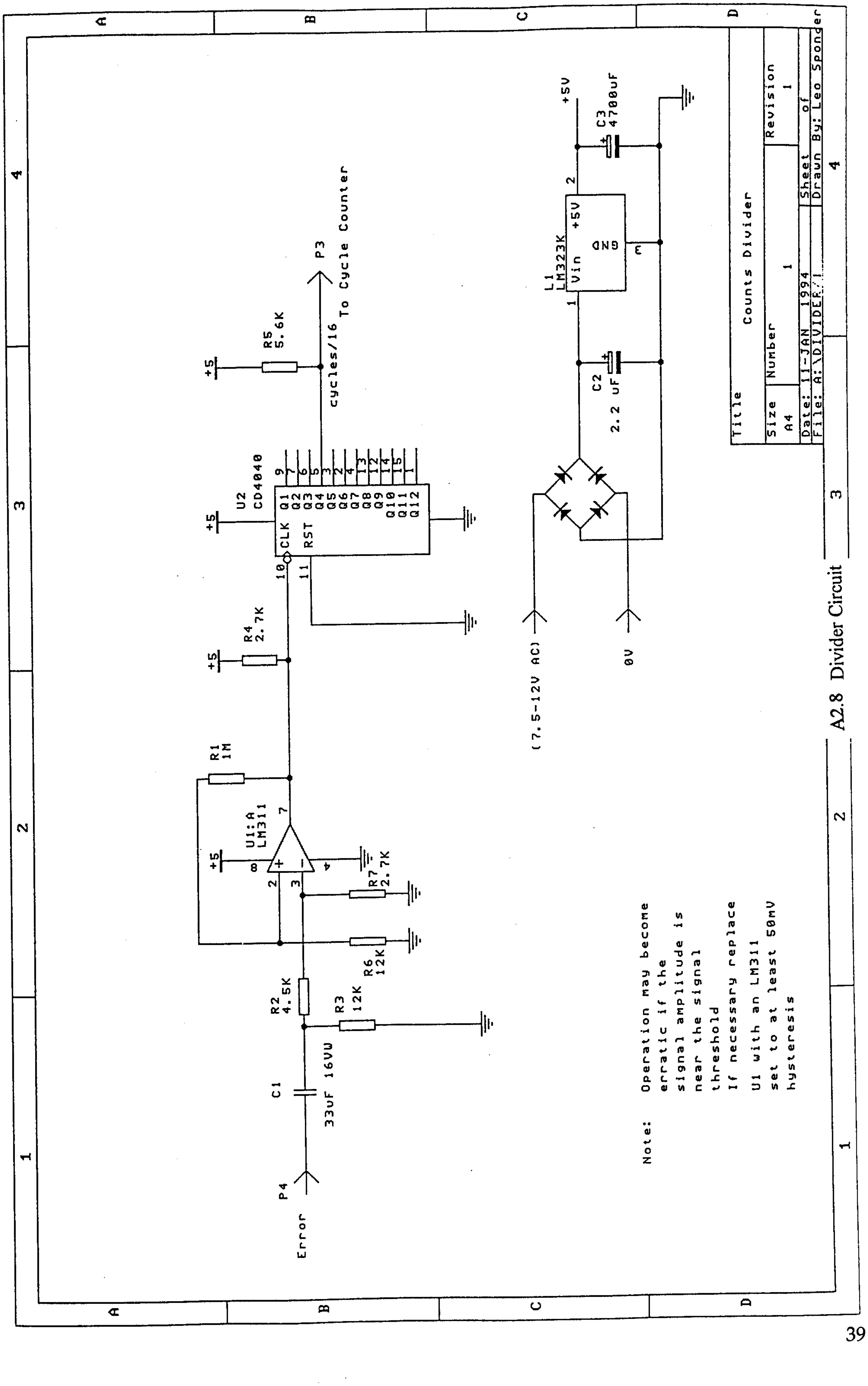
A2.5 Printed Circuit of Load Monitor



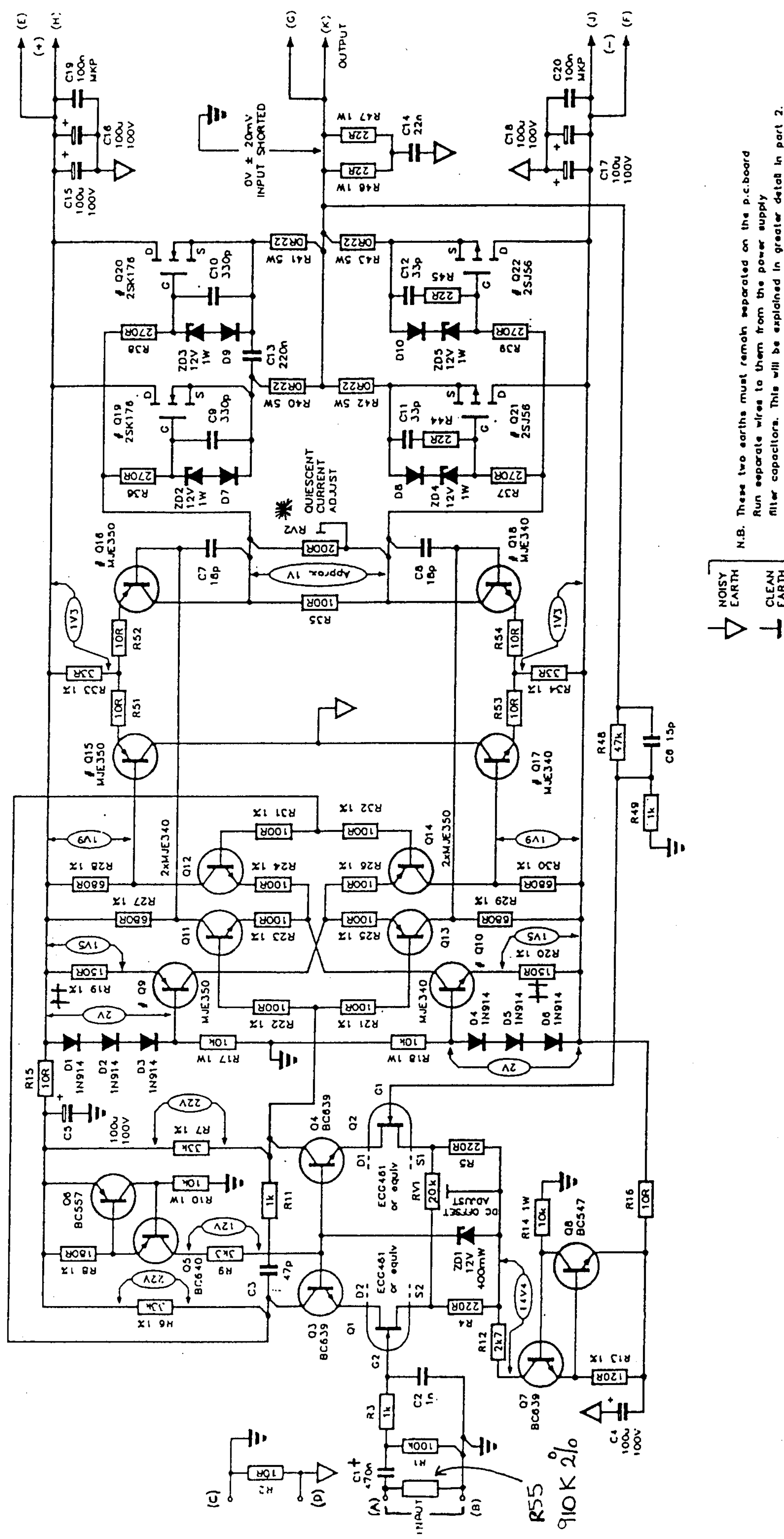
A2.6 Mute Circuit



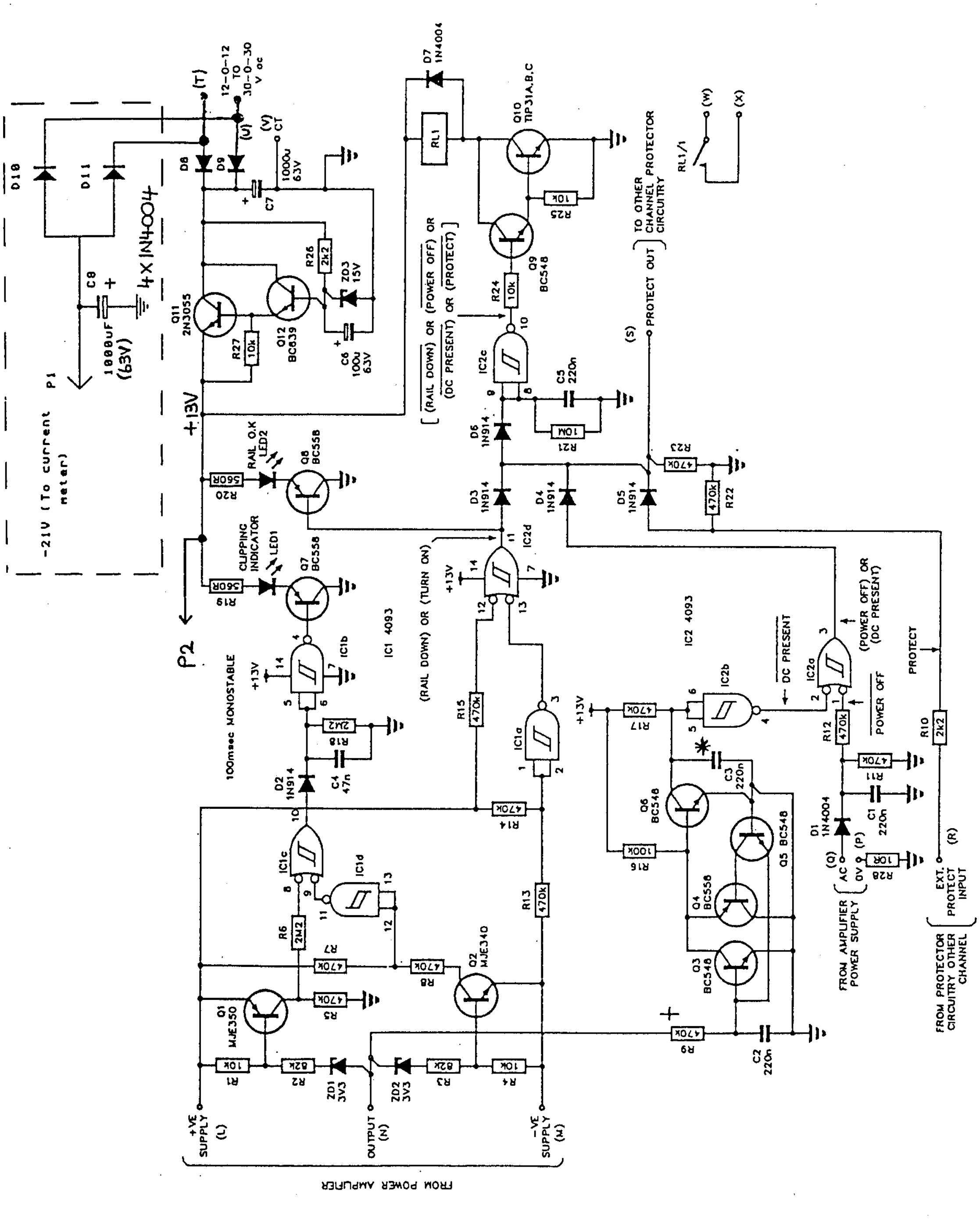
A2.7 Current Meter Circuit



A2.8 Divider Circuit



A2.9 Power Amplifier Circuit



A2.10 Shaker Protector Circuit

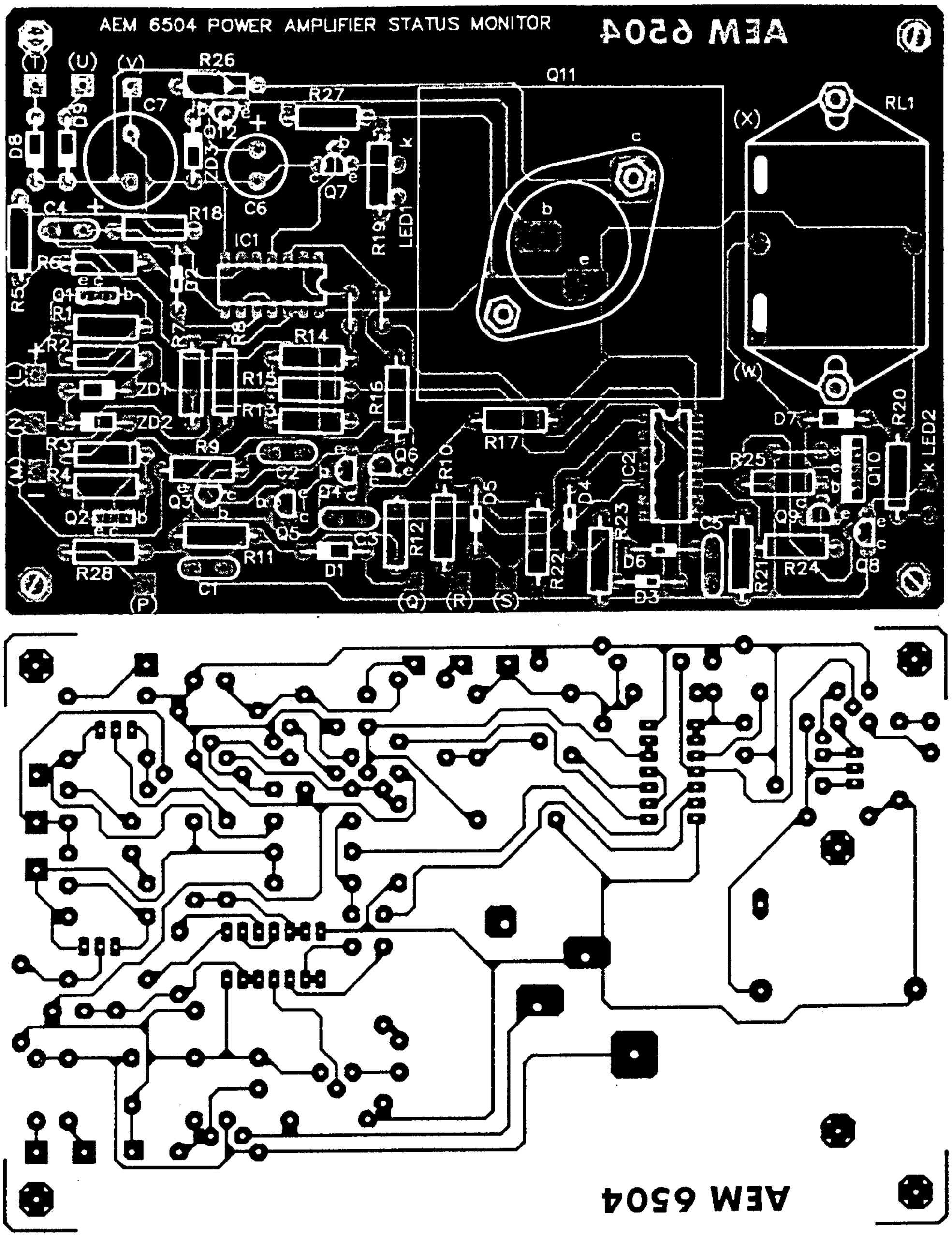


Fig. A2.11. Printed circuit and overlay for shaker protector circuit [3].

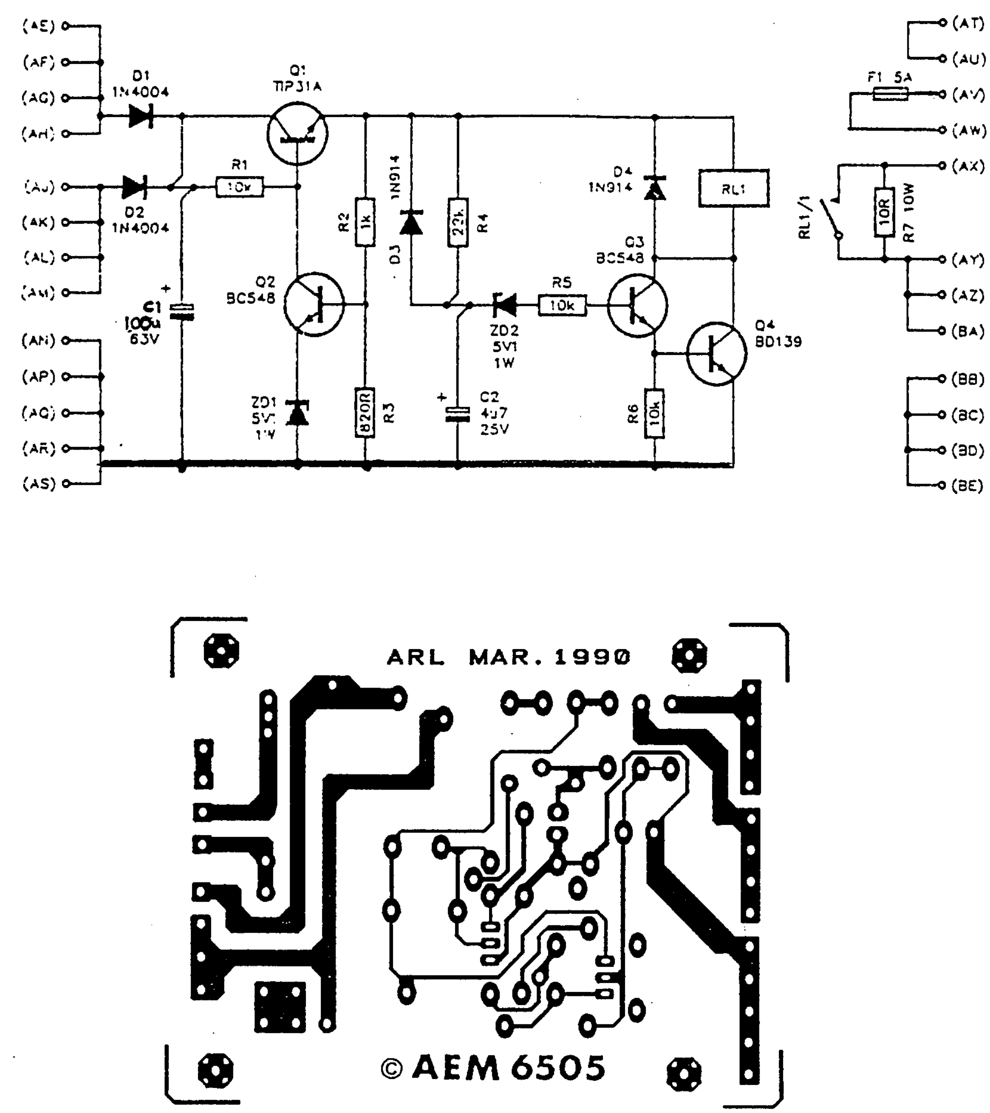


Fig. A2.12. Surge limiter circuit and printed circuit design [4].

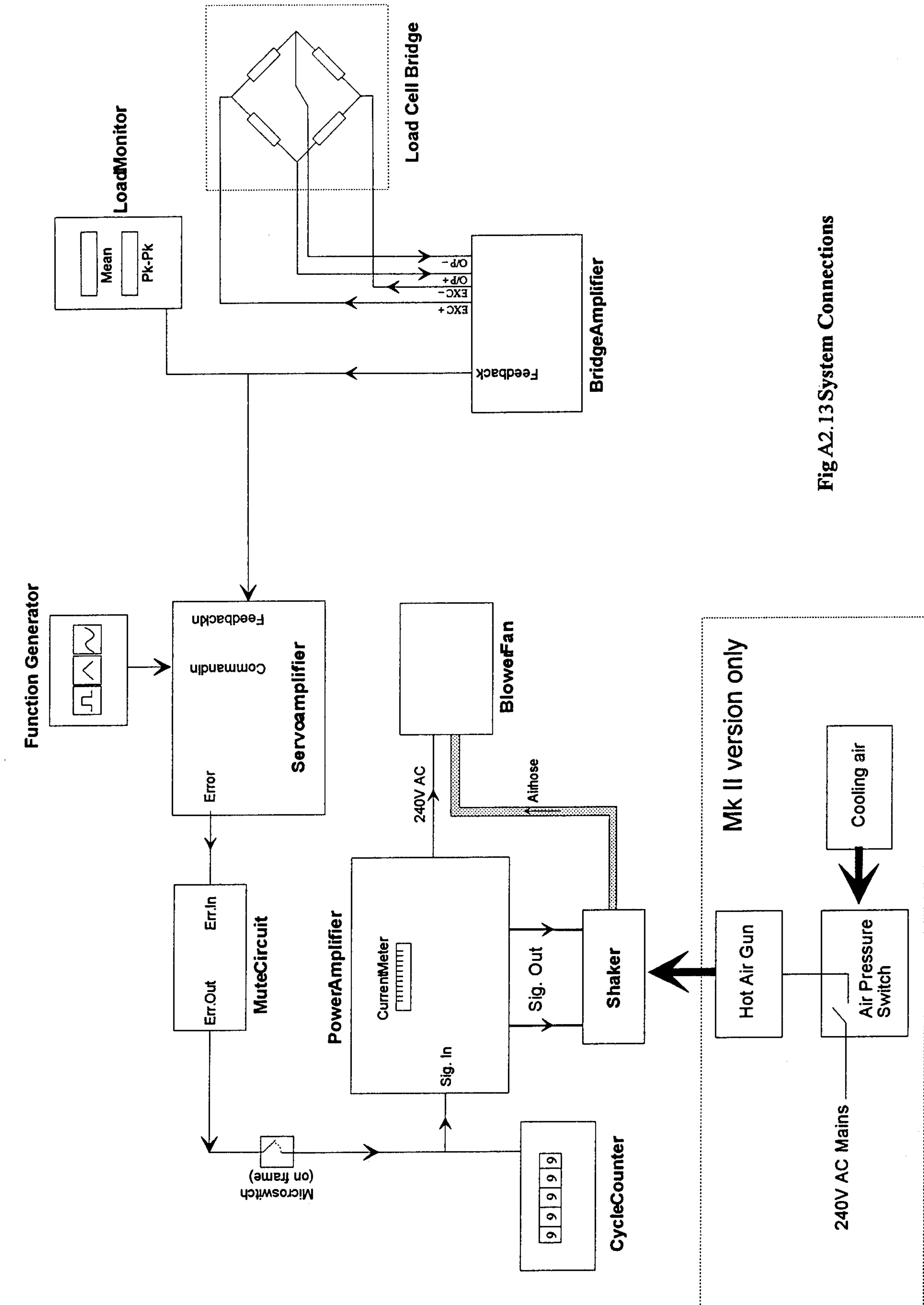


Fig A2.13 System Connections

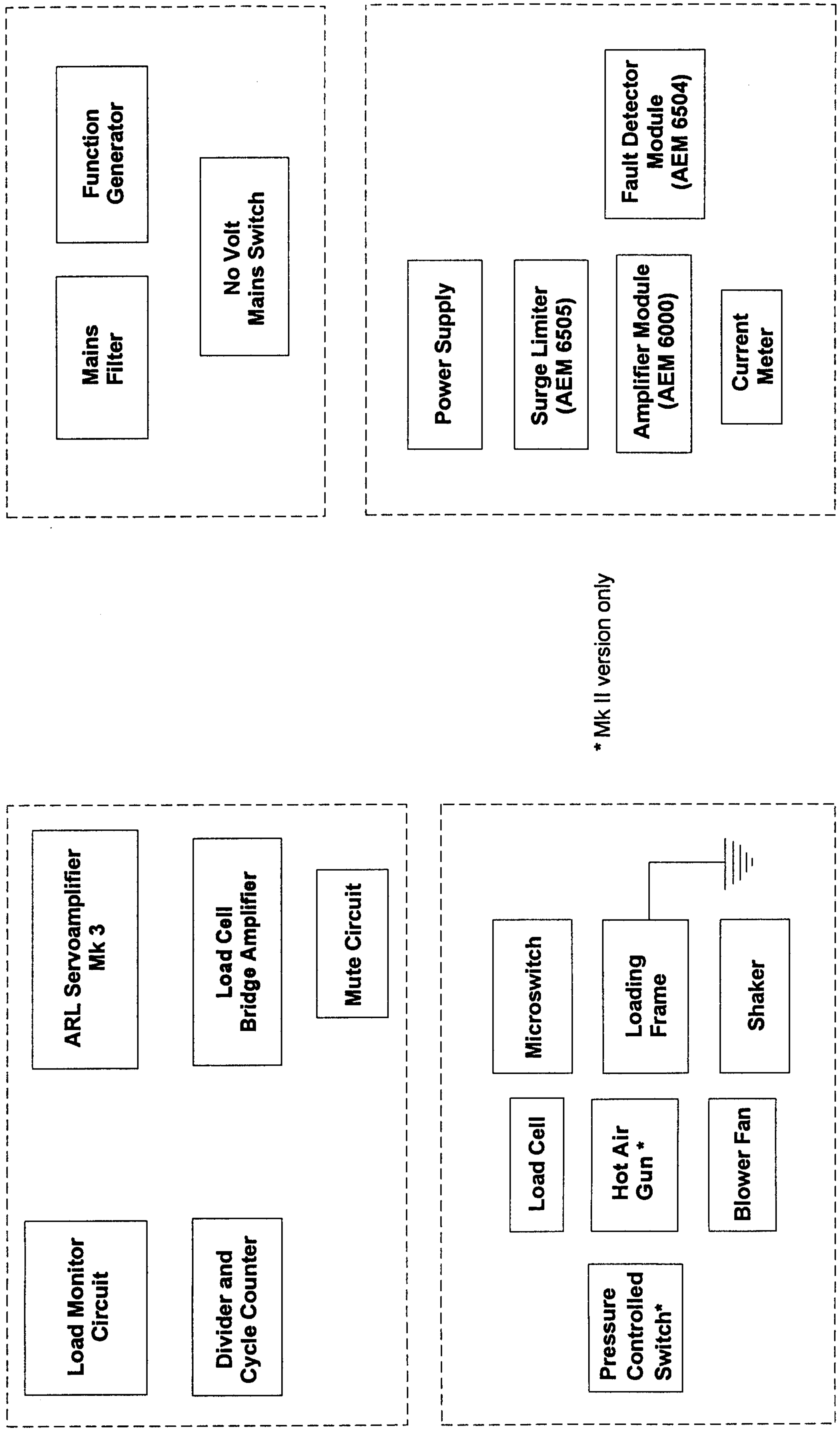


Fig. A2.14 Functional Units

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Appendix 3: Notes on Circuits

Modifications (Mk I)	Comments
RV4 (100K ohm) replaced with 25Kohm linear potentiometer.	Stability potentiometer, RV4, distorts the load waveform but reduces effects of resonance. This modification lessens the effect of this control.
R24A (100 ohm, W21) has been shorted. R17A has been changed to 24 ohm.	Increases the bridge excitation from 9V to 10V. giving an approximate 10% increase in bridge output. R17A is adjusted to give the required bridge excitation voltage.
R8A(220 ohm,Vishay) has been replaced with 560ohm, 1%.	The bridge gain was too high for this application. This modification reduces the load cell amplifier gain range to between about 95 - 475. The actual gain is determined by the BRIDGE GAIN potentiometer on the load cell amplifier front panel.
RV2 has been replaced with a fixed value 270 ohm, 1%.	RV2 controls the quiescent current in the output stage of the power amplifier and is not critical. The replacement used here gives approximately 100mA quiescent.
R55 (910K ohm, 2%), has been added across the signal input across input terminals (A) and (B).	This resistor bleeds charge from C1 to eliminate possible discharging through the driving circuit. Avoids possible surges when connecting or disconnecting signal sources.
An additional 0.68 uF has been paralleled across C1.	Lowers the low fequency cutoff (-3dB point) to around 2Hz. To reduce the low frequency limit to DC short out C1.
R19, R20 are 220 ohm, 1% types.	These were incorrectly labelled as 150 ohm, 1% on the original circuit diagram. This error is also detailed in [2] under Notes and Errata.
R9 changed from 470K ohm to 120K ohm.	C2, R9 form a low pass filter. Lowering R9 reduces the triggering sensitivity by raising the response frequency.
C3 changed from 0.22uF to 0.47uF.	This lowers the frequency at which the protector will trigger to about 2Hz.
Components added:- D10 - 1N4004 D11 - 1N4004 C8 - 1000uF (35VW)	These form a simple full-wave rectifier that supply the negative power rail (~ -21V) for the power amplifier current meter board (CM-1).
R7(10 ohm, 10W) has been replaced with a set of 3 parallel connected 100 ohm resistors, each 21W.	The inrush current for the twin toroidal transformers now used is higher than for the original types. The increased resistance and maximum total power for these resistors increases their reliability.
C1 (100 uF, 63VW) has been replaced with 220uF 63VW.	Original value allows excessive supply voltage ripple.
175V Metal oxide varistors, MV1, MV2 placed across output terminals of power amplifier.	These protect the power amplifier output stage from inductive emfs generated by the shaker coil.

1. AMRL drawing number
2. Australian Electronics Monthly magazine

Operations Manual for a Compact Electromechanical Fatigue Testing Machine

Leopold Sponder

DSTO-GD-0036

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ABSTRACT

This document gives details of the design and operation of two recently developed load controlled electromechanical shaker systems. These systems have been designed to test materials including composites, alloys and pure metals with either three or four point bending loads. One system (Mk I) is designed for room temperature testing only and the other (Mk II) can also be used at elevated temperatures.

The electronic control and drive circuits include new designs by the author, published designs modified by the author and circuits developed earlier at AMRL. The loading frame and ancillary hardware were designed and built at AMRL

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